TIMING OF RISK MANAGEMENT ACTIONS DURING THE CONSTRUCTION PROCESS: RELATIONSHIP WITH CONTROLLING PROJECT COST AND SCHEDULE IMPACTS

By

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ABSTRACT

Risk Management is a critical aspect of effective project control within the construction industry. Considering the fact that the construction process is subject to a diverse set of risk elements, the objective of this study was to better understand the risk distribution across the construction phase and the relationship between risk management actions and project cost and schedule performance. In the construction literature, many studies have analyzed project cost and schedule performance, qualitative perceptions regarding the relative importance of construction risk factors, and the cause, effect, and timing of individual change orders. This study contributes to the existing body of knowledge by providing an empirical understanding of the relationship between risk management actions taken by construction project teams and the corresponding impacts of the risks to budget and schedule. To investigate the influence of risk management actions on project performance, this study contributed a more detailed unit of measure than previous literature by systematically documenting all risk events (N=1502) encountered by project teams across the construction phase of 68 construction-building projects. New variables – risk resolution timing, risk active duration timing, and risk loading that have not been empirically measured in previous studies were introduced. Analysis was conducted through both descriptive and inferential statistical methods. The results included statistically significant relationships between cost and schedule performance and risk management actions at both the project-level (timing and magnitude of peak risk loading) and individual risk level (identification, resolution, active duration). The relationship between the risk management actions and the impacts of risks, derived from this study are useful for project management teams to understand in terms of the sheer complexity and amount of resources required to successfully manage the numerous potential risk impacts that face a construction project.

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CHAPTER I – INTRODUCTION

1.1 Background

The construction industry is subjected to high frequency and degree of risks. The industry's project-based structure presents a challenge for construction teams because every individual project is confronted by different requirements, a unique site layout, and varying cost and schedule constraints. The efficient performance of a project means delivering the construction projects on budget and under schedule within the original contracted scope of work. The construction project life cycle has risks associated with the procurement and contracts, even before the construction phase. In addition to these risks, numerous events during the construction phase, such as change in original scope of work, design error, contractor and subcontractor errors, unknown existing site conditions, unexpected weather, issues related to quality, safety, accidents, equipment and labor management, pose significant risks to complete the project within contracted budget, schedule, and quality requirements. When encountered, these risks often impact the cost and schedule of the project, possibly introducing change orders. The presence of such a diverse risk elements within the construction process necessitates strong risk management capabilities of the project team to efficiently deliver any project. This thesis focuses on the key skillset of risk management within the construction industry by studying risk management actions (risk identification, risk resolution, the active duration of the project team's risk mitigation response) of construction project teams along with the characteristics, timing, magnitude, and source of each individual risk the teams encountered during the construction phase. The study also involves understanding the impacts of risks, in terms of cost and schedule, and managing change orders to accommodate these risks as encountered across the construction project life cycle.

Individual risks encountered may precipitate into formal change orders during the construction phase that negatively affect the project budget and schedule. As a result of the complex nature of construction projects, project stakeholders at times view change orders as almost an inevitable part of the industry. Within this study, change orders are defined as an official deviation in cost and/or schedule of project from the original contracted scope of work. The impacts of change orders are known to have both direct impacts (cost and schedule adjustments) as well as indirect effects on the project (productivity loss, decreased quality, negative reputation, etc.) on the project (Ibbs 2005). At times, disputes between the client and contractor relationship may result from changes in the expectations established within original contract. This thesis systematically measured 1,502 identified risk factors that occurred across the construction phase of 68 vertical construction projects and documented associated timing and impact metrics of each risk.

1.2 Research Motivation

Understanding that construction projects are subjected to a high degree of risk, which may result in increases to the original contracted cost and schedule, project owners and construction industry stakeholders benefit by better understanding trends and best practices in risk identification, sources of risks, and impacts of risks within construction projects. In addition to this, empirical studies are important tools for project teams to understand the effectiveness of their risk management actions to control potential risk impacts. Existing studies lack empirical investigation of the relationship between the risk management actions of construction teams and corresponding risk impacts in terms of cost and schedule. This thesis addresses this gap in the literature and empirically investigates construction project risk characteristics, sources, impacts, and risk management actions along with their timing across the construction phase.

1.3 Research Objectives and Expected Contributions

The main objective of this study was to provide an empirical understanding and relationship between the risk management actions taken by construction project teams and the corresponding impacts of the risks on budget and schedule. The focus of this study was to examine whether the cost and schedule impacts were related to risk management activities of risk identification, resolution, and duration of risk mitigation activities. The data included primary and secondary data collected via a standardized risk tracking tool that was utilized by each construction project team that participated in the study. The standardized risk tracking tool is described in detail within the research methodology. The full data sample identified 1502 individual risk events within 68 building projects. The data sample was analyzed using statistical methods to better establish the relationship between the risk management actions of the project team and associated impacts to project cost and schedule. Findings from this study are intended to encourage future researchers to explore empirical datasets of individual project risk events, which would ultimately increase the number of measured projects and expand the type of projects to include a variety of industry sectors and scope types.

1.4 Thesis Outline

This work began by understanding and discussing the research objectives followed by understanding the needs and pragmatic importance of the study to the construction industry. The next step was the data collection phase, which involved direct involvement within on-going active construction projects to accumulate a full database of risk management information. The initial database included data from more than 100 construction projects collected from different owner organizations across North America. This data set was ultimately reduced to 68 projects based on different criteria, such as accuracy and completeness of data, from each individual project. The final data set was analyzed via multiple statistical methods in order to fulfill the research objectives. Later, the results were discussed and presented keeping in mind the usefulness of the study to the construction industry. The above mentioned information was organized in six different chapters as follows:

- Chapter 2 includes a thorough review of the existing literature pertaining to various related topics such as risk management, change orders, the various causes and effects of change orders during the construction phase, and general trends and measures of construction industry performance.
- Chapter 3 explains the gap between previous studies and the research conducted within this thesis. This chapter also presents the research questions, research hypotheses, and claimed contribution of the research.
- Chapter 4 describes the research methodology adopted for this study, including the data collection process, the data collection tool, and characteristics of the data sample. Definitions of independent and dependent variables are also included. This section also provides a detailed description of the method of analysis used to perform statistical testing of hypotheses.
- Chapter 5 presents results of the research based upon both descriptive and inferential statistical tests, including graphical and tabular representations.
- Chapter 6 discusses the key findings and identifies practical implications for professional practice within the construction industry.
- Chapter 7 concludes this thesis by capturing the research objectives, associated methodology, and major findings. Specific contributions of the study are specified. Limitations are identified along with recommendations for future research.

CHAPTER II – LITERATURE REVIEW

2.1 Introduction

Because of the complexity in the construction industry, considerable efforts were made to identify the sources and effects of risks affecting the construction industry. This chapter provides an overview of the studies related to risk identification, first step in project risk management, change orders, causes and effects of change orders and studies documenting quantitative measures of construction industry performance.

2.2 Risk Management as a Project Management Competency

According to the Project Management Body of Knowledge (PMBOK) Guide (2008), published by the Project Management Institute (PMI), project management is defined as a profession that is based upon the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. The PMBOK prescribes professional best practices for risk management within a project management context. As a result of PMI's assertion that all projects entail a certain degree of risk, the PMBOK advocates the inclusion of risk management plans within the projects' regular operations. The PMBOK defines risk as an uncertain event or condition that, if it occurs, has a positive or negative impact on one or more project objectives such as scope, schedule, cost, and quality. The PMBOK's best practices for risk management activities includes the following:

- Identify Risks: Involve the right people who know the potential risks, assign a risk owner, use methods to identify risks and sources, and document risks within a risk register.

- Qualitative Risk Analysis: Pre-plan for potential risks in a rank-ordered fashion by estimating the probability of a risk occurring as well as a magnitude of the potential impact to arrive at a qualitative score for each risk item.
- Quantitative Risk Analysis: Quantitative methods are implemented for important risks which can be quantified. Analysis methods may include sensitivity analysis, Monte Carlo simulation, or definition of expected monetary values.
- Plan Risk Reponses: The PMBOK defined four risk strategies which may be implemented to respond to a risk, once it has been identified, as follows:
    - Avoid: do not engage in the risky action and, if possible, circumvent the risk altogether.
    - Transfer: assign the risk to another party, typically to a separate project stakeholder. Risk transfer capabilities within a project are typically defined by contractual relationships and may incorporate insurance and bonding information.
    - Accept: let the risk happen and engage contingency reserves in the project cost, schedule, or performance arenas.
- Control Risks: Continually re-assess new and existing risks, perform variance and trend analysis to accurately gauge potential impacts to overall project success factors. Ensure that risks are always monitored to maintain the project team's focus on achieving project outcomes.

The PMBOK notes that project management core competencies include understanding the scope, quality, schedule, budget, resources, and risks to deliver a project successfully. These factors have a relationship that change in one factor often affects the other. For instance, a change in scope is often accompanied by the change in budget and schedule of the project. Also the identified risk on the project affects its quality, cost and budget. Thus, the relationship of risk impacts makes it essential for the project management team to manage these factors throughout the project's life cycle.

Similarly, in construction projects, these factors play a vital role in delivering the project based on the stakeholder requirements. This study focuses on the risk management in construction projects understanding the risk identification and managing the change orders generated from identified risks.

2.3 Risk Management in Construction

Risk management is the process of defining how to conduct risk management activities for a project. It includes factors such as project scope, cost management, schedule management, communications between the project parties, etc. (PMBOK Guide 2008). The projects with increasingly complex scopes and unique conditions are subjected to more risks and require better pre-planning and risk management (Bosch-Rekveldt et al. 2011). Construction projects are unique projects because of the myriad conditions and unknown events, which make risk management an important part of the project (Hilson 2009).

Risks in the construction industry are defined as the threats and opportunities to the project cost and schedule. This implies that risks are events faced during the project life cycle that impact cost and schedule in negative as well as positive ways. According to the Project Management Institute (2010), risk management is a vital measure for the efficient delivery of projects. The construction Industry Institute (CII) describes risk management as the continuous process throughout the life cycle of the project. In addition, CII describes the three phases of risk management

- Identification
- Measurement
- Management

This thesis describes the risk identification based on the characteristics and sources of risk in 68 construction projects. The second phase, measuring the impact of risk in terms of cost and schedule, follows the risk identification phase. The third phase describes the management of change orders associated with the risks identified on the projects.

2.4 Risk Identification

Various studies used different methods to categorize the sources, or causes, of risks identified within construction projects. Hanna et al. (2013) used three-phase survey methodology to collect the data and identify the risks with high potential for conflict and associate these risks with the projects players. The data collection was based on an initial questionnaire, followed by a web based survey, and follow-up phone interviews in order to develop a risk allocation model. The single-party risk assessment worksheet was developed for internal risk management and the two-party risk assessment worksheet for external risk management. These two worksheets together formed a risk allocation model for identifying the risks. The sources of risks are important so as to allocate the risks. The source is the project stakeholder responsible for the risk, for instance source can be clients, contractors, designers, suppliers, or third party like government agency. General contractors have been shown to contribute more to risks resulting in schedule impacts on building projects (Smithwick et al. 2015).

2.5 Change Orders in Construction

Change orders are at times viewed as an inevitable part of construction industry because of the dynamic nature and uniqueness of the construction operations (Alnuaimi et al. 2014, Hanna and Swanson 2007). According to the American Institute of Architects (Article 12.1.1 of AIA A201 1977), a change order is defined as a written order to the contractor signed by the owner and architect, issued after execution of the contract, authorizing a change in the work or an adjustment in the contract sum or the contract time. In layman's terms, a change order is defined as alteration of the original contracted scope of work between the owner and contractor, arising from many factors, including design errors, design changes, additions to the scope, or unknown conditions (Hanna and Swanson 2007).

There are numerous reasons leading to change orders on construction projects such as project scope changes, schedule delay due to natural events, design variations, etc. (Sun and Meng 2009, Hsieh 2004, Taylor et al. 2011). The resulting impacts of change order affects both the owner and contractor organizations (Hanna et al. 1999). Industry players such as clients, contractors, and consultants, may all be responsible for change orders on the projects (Sun and Meng 2009, Rosenfeld 2014). Change orders negatively impacts the projects by increasing the cost and schedule of the projects. The change orders also have positive effects, along with the negative effects on the projects (Ibbs 2005). The change order literature review identified that common research methodologies followed data collection approaches of questionnaire surveys, case studies of industry projects, interviews with industry experts, and documentation reviews from industry projects to identify and list the causes and effects of change orders in construction industry.

2.6 Causes of Change Orders

The literature review included papers and articles regarding the reasons and causes leading to changes in the construction projects. Chan and Kumaraswamy (1997) undertook a survey to identify the causes of schedule delays in construction projects in Hong Kong. The survey included different parties of the construction industry such as clients, contractors, and designers/consultants. Prior to the survey, a questionnaire consisting of 83 factors causing delays in construction projects was prepared, categorized in eight major groups as project related, client related, design team related, contractor related, materials, labor, plant/equipment, and external factors. The researchers received 147 responses from experienced industry members involving both building projects and civil projects. The survey results were collected and analyzed to identify the 20 top factors causing construction delays. The variables used to rank the factors included the relative important index, rank agreement factor, and percentage disagreement. A strong agreement between the clients and consultants were noted using a cross comparison technique. All the three key stakeholders within the construction industry agreed on poor site management and supervision, unforeseen ground conditions, low speed of decisions making involving all project teams, client initiated variations and necessary variation of works as the principal delay factors.

Taylor et al. (2011) included an analysis of change orders across 610 roadway construction project in the state of Kentucky. The data documented 610 projects and change orders from 2005 to 2008, arising between 2005 and 2008. Based on the descriptive analysis, the contract omission had the highest frequency for the change order followed by contract item overrun, which also has the highest average change order dollar amount. The ANOVA test was used to analyze the change order data based on type of construction and also by new construction versus maintenance work. The major finding from analyzing the collected data and interviewing the Kentucky Transportation

Cabinet expert, pointed the leading causes of change order as contract omissions, owner induced enhancements, and contract item overrun.

Rosenfeld (2014) indicated cost overruns within construction projects to be a global problem. The research used expand-focus approach to analyze the root-cause of cost overruns in construction projects all over the world. The two phase expand-focus approach narrowed down the vast list of 146 potential causes of cost overruns, identified from international literature survey and industry expert brainstorming, to 15 universal root causes of cost overruns. A cross sectional survey was conducted among the 200 engineers, with average work experience of 16 years, representing different players (client, contractor and designer) of the construction industry. The three major root causes of the cost overruns that were ranked outstanding by the surveyors are 1) Premature tender documents, 2) Too many changes in owners' requirements or definition, and 3) Tender-winning prices are unrealistically low (suicide tendering). The lead causes, as identified using the survey results, were statistically analyzed using the spider chart analysis and spearman's rank correlation.

Assaf and Al-Hejji (2006) conducted a field survey among 23 contractors, 19 consultants and 15 clients, on 76 public and private construction projects. They listed 73 causes of delay through literature review and discussion with the construction industry players. They categorized the 73 causes of delay in following nine groups: factors related to project, owner, contractor, consultant, design-team, materials, equipment, manpower and external factors. The three indices, namely frequency, severity and importance, were used to rank the factors causing delay in the projects. Labor related, owner related and project related factors were the leading causes of delay as ranked by the owner, contractor and consultant respectively. Spearman's correlation was used to validate the agreement between the parties. Labor and contractor factors are important causes of delay as agreed upon by the owner and consultant (72.4%) whereas related factors are important as agreed upon by the owner and contractor (56.8%). The research concluded that the change order itself is the most common cause of delays in construction projects.

Sambasivan and Soon (2006) distributed a questionnaire survey to the clients, contractors, and consultants to identify the causes of delay and its effects on the construction project The study received 150 responses which included a survey with 28 pre identified delay factors categorized into eight major groups, namely client related causes, contractor related causes, consultant related causes, material related causes, labor and equipment category causes, contract related causes, contract relationships related causes, and external causes. A relative important index and spearman's correlation was used to rank and check the agreement between responses from the industry players. The analysis resulted main causes of delay as contractor's improper planning, contractor's poor site management, inadequate contractor experience, inadequate client's finance and payments for completed work, problems with subcontractors, shortage in material, labor supply, equipment availability and failure, lack of communication between parties, and mistakes during the construction stage.

Hsieh et al. (2004) conducted a study on data collected from 90 completed metropolitan public works projects that experienced change orders in Taiwan. After examining the collected data regarding change orders, they divided causes of change orders into two major groups as technical and administrative. The technical group was further divided into planning and design, underground conditions, safety considerations and natural incidents. Whereas the administrative group was divided into changes of work rules/regulations, changes of decision making authority, special needs for project commissioning and owner transfer and neighborhood pleading. To quantify the effects of change orders, seven indices were developed as follows: Change order ratio, change order ratio in addition, change order ratio in subtraction, frequency of change orders, proportion of change order, contribution degree, schedule extension degree. The seven indices were analyzed using statistical correlation and variance analyses and it resulted in planning and design as the most prominent factor for change order.

Alnuaimi et al. (2010) conducted a case study on four different projects in Oman to conclude the causes and effects of change order on construction projects. The questionnaire consisting of 42 questions was distributed among 30 different clients, 25 contractors and 20 consultants to obtain feedback for the causes and effects of the change order. Out of many causes included in the survey, the "owner instructs additional works" is the most common cause of change as agreed upon by all the three parties. The other causes of change order included owner modification to design, non availability of construction manual, procedures and engineering license to maintain quality work, poor communication between different parties, lack of overall planning, etc. in descending order as ranked by the three parties with last being poor management by the contractor.

Sun and Meng (2009) conducted a study of existing literature on construction project change order causes. The study included reviewing and analyzing 101 journal papers and 6 major research reports. The literature review resulted in categorizing the identified causes of change orders to project related, client related, design related, contractor related, and external factors. The effort of reviewing the existing literature resulted in three level taxonomy of change orders causes as 1. external causes (environmental, political, social, economical and technological factors), 2. organizational causes (process, people, and technology related), and 3. project internal causes (client, design, and contractor generated).

Hanna and Gunduz (2004) conducted a study on 34 small construction projects with the help of the Construction Industry Institute and listed reasons for the change orders in small construction projects as lack of planning and management in preconstruction phase, inadequate schedule for cost and labor, duration of small project leading to speed up the construction, incomplete design during construction phase, insufficient management, etc.

Hanna and Swanson (2007) conducted a research that centered at the types of changes a construction projects can experience and the impact the change orders has on the projects. Due to the Insufficiency in planning and availability of resources, the changes that effect the construction projects can be categorized as directed change (change as agreed upon by all the parties as an actual change), constructive change (increase in scope of original contracted work), and cardinal change (breach of the contract by the owner).

The literature investigating the causes of the change orders identified common sources as client, consultant/designer, contractor, or unforeseen conditions on the project site. Main reasons causing changes on the projects are, but not limited to premature tender documents, scope change initiated by the client, poor site management, contract omissions, materials delay by suppliers, contractor and subcontractor errors, labor problems, experience of contractor and labors, poor communication between the parties, delay in decisions and payments from client but also the unforeseen conditions on site and unforeseen events like natural calamities leads to project change orders. The most common and frequent causes leading to change orders were variation in original contracted scope of work (owner-directed scope changes) and design errors or omissions from the consultant. The literature related to the causes of change orders as a part of this study will assist the project management team in understand the potential causes of change order and hence manage the risks accordingly.

2.7 Effects of Change Orders

Change orders that are identified across the project lifecycle affects construction in both negative and positive ways. The following literature review was conducted to understand and identify the effects of the changes on the construction projects. Ibbs (2005) conducted a study on data of 162 construction projects obtained from 93 contractors. The researcher analyzed the impact of changes on the projects using statistical methods and also the timing of change orders. According to author, change is defined as the variation to the original scope of work, both tangibly and intangibly. The effects of change in a project is divided in to two groups, discrete and cumulative impacts. The discrete effects are the direct effects on the cost and schedule of the project whereas cumulative effects are defined as the unforeseeable disruption of productivity resulting from rippling effect of change order in a project. The regression analysis of the data concluded that the changes that occur later in the project are more adverse to the labor productivity compared to those that occur early in a project. One of the main reason for the change in later stage is the addition to scope as concluded from the research.

Hanna et al. (1999) conducted a study and concluded that change orders as accepted by both owners and contractors, impacts the labor efficiency in addition to increased cost, scheduling conflicts, breaking of project momentum, increased overhead, etc. Data regarding 61 mechanical construction projects from 26 different contractor were collected and analyzed using regression process to develop statistical model to quantify the impact of change order on labor efficiency. Moreover, the study also considered the timing of change as an independent variable which concluded that later the change is experienced, the higher is the impact it will have on productivity.

A study conducted by Serag et al. (2010) included 16 Florida DOT projects from 16 different contractors to develop statistical model to quantify the impact of change orders on project cost. The field of heavy construction experiences change orders because of errors and omissions, scope of work changes, or changes due to unforeseen conditions. Change in a project, not only impacts the direct cost change but also impacts the indirect costs such as higher insurance rates, delayed completion projects, and lost opportunity of bidding in other projects.

Hanna and Swanson (2007) studied the change effects on projects and concluded that the changes effects the project in many ways including financial loss and loss of productivity. The change orders has a cumulative effect on the project. The research looks at the past and recent legal court decisions related to change orders in the construction industry and outlines liability, proving causation and resultant injury as the three elements of cumulative impact claims. The author describes cumulative impact of change order on the project as the impact on the labor productivity and working efficiency of the contractor.

Hanna and Gunduz (2004) conducted a study on 34 small construction projects with the help of the Construction Industry Institute to quantify the impacts of change orders. They listed reasons for the change orders in small construction projects as lack of planning and management in preconstruction phase, inadequate schedule for cost and labor, duration of small project leading to speed up the construction, incomplete design during construction phase, insufficient management, etc. A questionnaire consisting the factors causing change orders were distributed to the mechanical and electrical contractors and the responses were recorded with the help of CII committee. Regression analysis was performed on the variables recorded as a part of answers to the questionnaire, resulted in a model to quantify the impact of change orders on the labor productivity. The model developed was cross validated, yielded approximately 70% of accuracy.

Sun and Meng (2009) conducted a study of existing literature on construction project change order causes and effects on the project. The factors leading to change order has direct and indirect effects on the project. The direct effects were related to time and cost whereas the indirect effects were related to productivity, risk, and numerous other effects such as poor relationship between the parties, safety and quality concerns, and claims because of disputes in the projects. The effort of reviewing the existing literature resulted in three level taxonomy of change orders effects as 1. Time effect (time extension, loss of productivity, increased risk), 2. Cost effect (direct cost increase and indirect cost increase), and 3. Relationship and people effect (relationship related, working conditions, and staff related).

Alnuaimi et al. (2010) listed the most prominent effects resulted from the change order as "delay completion date of projects" followed by "claims and disputes", "cost overruns", "adversely affect the performance and moral of labor", "most contractors incur additional costs" and "effect work quality" as ranked by the participating clients, contractors and consultants.

Sambasivan and Soon (2006) identified the causes and studied the impacts of change orders on the construction projects. The effects of changes on projects can be described in five main ways as time overrun, cost overrun, disputes, arbitration, litigation and total abandonment.

From the above literature, it was concluded that change orders, to some extent, could have direct impacts on each project stakeholder within the construction industry. The impacts of change orders on the project are direct in terms of cost overruns and schedule delays. In addition to direct impacts, the change order also has indirect impacts on projects which includes the negative effects on labor efficiency, chances of disputes between the industry players, break in the momentum of work, additional increase in overhead and insurance costs, etc. Change orders also have cumulative impacts on the projects decreasing the productivity. To some extent, change orders have impacts at business level such as higher insurance rates, delayed completion projects, and lost opportunity of bidding on the other projects. Moreover, the impacts of change orders are also related to the timing of when they occur on the project schedule.

2.8 Construction Industry Performance

Construction projects are often viewed as being subjected to high rates of change as compared to other industries based on the high risks faced due to unique nature of the projects (Hilson D 2009). Change orders are prevalent in construction projects and often impacts the project cost and schedule (Alnuaimi et al. 2010). Quantitative performance of construction projects can be measured in terms of cost and schedule overruns. A construction project is commonly considered to be successful if the project is completed on contracted schedule time and within budget without compromising the specified standards of quality (Chan and Kumaraswamy 1997). A project that is completed without a single change order, cost and schedule overrun, is simply not possible without a complete accurate design, as well as proper coordination and communication during the construction phase (Hanna and Swanson 2007). It is common for construction projects to be completed in a fashion that deviates from the original contracted budget and schedule (Assaf and Al-Hejji 2006). Following literature review was performed as a part of this study, to understand the construction industry performance in terms of cost and time.

Cantarelli et al. (2012) conducted a study that included 78 different infrastructure projects of road construction, rail construction and fixed link projects such as bridges and tunnels in Dutch construction industry to identify the performance of projects in terms of cost. The 37 road construction projects showed an average cost increase of 18.6% with standard deviation of 38.9, whereas 26 rail and 15 fixed link projects showed an average cost overrun of 10.6% and 21.7% with a standard deviation of 32.2 and 54.5, respectively. Another Cantarelli et al. 2012 concluded an average change in cost of 16.5% with a standard deviation of 40 which included 78 transportation infrastructure projects in Netherlands.

Cantarelli et al. (2012) conducted a study to compare the Netherlands construction project cost performance to the rest of the world. Overall, including the Netherlands construction projects, a total of 806 infrastructure projects were studied which included 537 road projects, 195 rail projects, 36 tunnel projects and 38 bridge projects. The cost overruns in road, rail, bridges and tunnels projects were recorded as 19.8%, 34.1 %, 30.3%, and 35.5 %, respectively.

Chen et al. (2016) collected secondary data on all together 418 Design-Build projects within the commercial/institutional, civil infrastructure, and industrial sectors to examine the time and cost performance. The analysis measured performance via four variables namely time overrun rate (TOR), early start rate (ESR), early completion rate (COR) and cost overrun rate (COR) to understand the performance of projects. The analysis of the collected data showed an average TOR of 0.15% ranging from 52% time saving to 169% delay while average COR of 6.9% with range of saving of -38% to an increase of 286%.

Flyvbjerg et al. (2003) conducted a study covering 258 infrastructure projects from 20 nations to determine and analyze the cost overruns in construction industry. The project cost data was collected using different sources which included project accounts, interviews with the project team, and questionnaires. The results showed an increase in cost on almost nine out of 10 projects. The average increase in cost for 258 projects was 27.6% with a standard deviation of 39.

Migliaccio et al. (2010) studied 146 Design-Build projects collected from DOTs of 15 states to understand the project performance. The project data showed cost growth ranging from a low of - 56% to a high of 84%, with an average of 0.4% across the projects. The schedule growth on the projects under study was ranged from a low of -58% to a high of 118%, with an average of 13%.

Odeck (2003) conducted a study to understand the relationship between estimated and actual cost of projects. The data sample included 620 road projects from Norway. Out of the 620 projects overall, only 75 projects didn't experience the change in cost. Whereas the remaining projects, showed an average change in cost of 7.88% with standard deviation of 29. The highest underrun and overrun in the cost was recorded as -58.5% and 182.7% respectively.

Perrenoud et al. (2014) conducted a study on 266 capital projects collected from a single client from 2005 to 2011. The research was performed to understand and measure the performance of the projects in terms of cost and schedule associated with the risks identified across each project. The finding shows an average increase in cost of 3.2% and increase in schedule by 48.9% across 266 projects under study.

Perrenoud et al. (2015) collected data on small 229 design-bid-build building projects from a university based in USA to study risk distribution across the project and effects of risks on the performance of project. The projects with an average awarded cost and schedule of $344,969 and 87 days respectively, were considered for the research. The finding shows an overall increase in cost of 8.4% compared to a high increase in schedule of 39.2%.

Riley et al. (2005) studied 120 construction projects performed by same contractor to understand the performance of projects based on different delivery systems. The analysis showed that design-build projects has less change orders compared to design-bid-build projects. Out of total projects, 65 design-build projects showed a cost increase of 4.7% compared to 16.6% increase in remaining 55 design-bid-build projects.

Rosner et al. (2009) conducted a study on 835 military construction projects to study the performance based on the delivery methods. The data consisted of 278 design-build and 557 design-bid-build projects over fiscal years 1996-2006. The finding shows an average cost increase of 4.5% and 6.4% in design-build and design-bid-build projects respectively. Whereas, an average schedule growth was noted as 17.3% and 18.8% in design-build and design-bid-build projects respectively.

Serag et al. (2010) studied 16 Florida DOT projects to quantify the impacts of change orders on the project cost. The project data was collected from transportation department of Florida ranging from $10-$25 million. The finding showed an increase in contracted cost of projects from 0.01% to 15%.

Shehu et al. (2014) conducted a study including 359 completed projects in Malaysia to understand the cost growth in the construction industry projects. The data sample mainly consisted infrastructure projects, educational building and residential projects and most of them were design-bid-build projects. Overall, an average increase of 2% in the cost with standard deviation of 16 indicated a balance of negative and positive variances in the projects. An average increase in cost of 11.7% was recorded among positive overrun projects.

Konchar and Sanvido (1998) studied project specific data collected from 351 US building projects and analyzed the data to compare the performance of projects based on the delivery methods. Out of total data sample, 80 projects were delivered using construction management at risk whereas 116 and 155 projects were delivered using design-bid-build and design-build respectively. Construction management at risk recorded cost overrun of 3.37% and schedule delay of 0%. The design-bid-build and design-build showed cost overrun of 4.8% and 2.2% respectively whereas schedule delay rate of 4.44% and 0% respectively. The analysis showed overall cost growth of 3.3%.

Hale et al. (2009) studied 38 design-build and 39 design-bid-build military building projects to compare the performance of project in terms cost and schedule. The study showed an average increase in cost of 2% in design-build projects and 4% in design-bid-build projects. The average increase in schedule for design-build and design-bid-build was recorded as 11.5% and 13.8%. Overall, the research showed that the design-build projects performed well as compared to design-bid-build.

Bogus et al. (2013) compared design-build wastewater projects and transportation project to study the project performance in terms of cost and time. The study included 47 wastewater and 146 transportation projects. The average cost increase in wastewater projects and transportation project was recorded as 2% and 0.4 % with standard deviation of 6.3% and 16 % respectively. Similarly, the average schedule growth in wastewater and transportation projects was recorded as 6% and 13 %with standard deviation of 27% and 29%, respectively.

Ojo et al. (2010) studied 68 building projects in Nigeria to understand the performance of construction projects based on the delivery methods. The study included 53 traditional design-bi-build projects and 15 design-build projects. The results showed an average cost overrun of 42.6% in design-bid-build projects with a standard deviation of 22.1, and 21.4% in design-build projects with standard deviation of 14.2. The average schedule increase in design-bid-build and design-build projects were recorded as 135.9% and 36.3% with a standard deviation of 20.1 and 17.3, respectively.

2.9 Chapter Summary

The above literature confirmed that project changes in terms of cost overrun and schedule overrun are a common occurrence within the construction industry. Moreover, the cost overrun and schedule overrun in construction industry is a global phenomenon (Flyvbjerg et al. 2003). Table 2.1 summarizes the recorded changes in cost and schedule based on the literature review. A weighted average of the quantitative change order data reported in the literature arrived at a change order rate of 10.42% for all construction sectors, and 6.06% for building projects. Schedule performance was found to have an average overrun of 12.85% for all construction sectors and 17.16% for building projects. Note that the majority of projects were new construction as opposed to renovations or redevelopments.

Table 2.1 Construction Industry Performance

Sr No.	Literature	Type of Projects	Delivery Method	Number of Projects	Cost overrun	Schedule Overrun
1	Cantarelli et al. 2012	Road	-	37	18.6%	-
		Rail	-	26	10.6%	-
		Fixed Link	-	15	21.7%	-
2	Cantarelli et al. 2012	Infrastructure	-	78	16.5%	-
3	Cantarelli et al. 2012	Road	-	537	19.8%	-
		Rail	-	195	34.1%	-
		Tunnel	-	36	30.3%	-
		Bridge	-	38	35.5%	-
4	Chen et al. 2016	Commercial/Institutional/Infrastructure/Industrial	Design-Build	418	6.9%	0.15%
5	Flybjerg et al. 2003	Infrastructure	-	258	27.6%	-
6	Migliaccio et al. 2010	Transportation Projects	Design-Build	146	0.4%	13.0%
7	Odeck 2003	Road	-	620	7.9%	-
8	Perrenoud et al. 2014	Capital Projects (Building)	-	266	3.2%	48.9%
9	Perrenoud et al. 2015	Building Projects	Design-Bid-Build	229	8.4%	39.2%
10	Riley et al. 2005	Building Construction Projects	Design-Build	65	4.7%	-
			Design-Bid-Build	55	16.6%	-
11	Rosner et al. 2009	Military Building Construction Projects	Design-Build	278	4.5%	17.3%
			Design-Bid-Build	557	6.4%	18.8%
12	Serag et al. 2010	Transportation Projects	-	16	15.0%	-
13	Shehu et al. 2014	Infrastructure/Educational Buildings/ Residential	Design-Bid-Build	359	2.0%	
14	Konchar and Sanvido 1998	Building Projects	CM at Risk	80	3.4%	0.0%
			Design-Build	116	2.2%	0.0%
			Design-Bid-Build	155	4.8%	4.4%
15	Hale et al. 2009	Military Building Construction Projects	Design-Build	38	2.0%	11.5%
			Design-Bid-Build	39	4.0%	13.8%
16	Bogus et al. 2013	Wastewater Projects	Design-Build	47	2.0%	6.0%
		Transportation Projects	Design-Build	146	0.4%	13.0%
17	Ojo et al. 2010	Building Projects	Design-Build	15	21.4%	36.3%
			Design-Bid-Build	53	42.6%	135.9%
				Weighted Average	**10.42%**	**12.85%**
				Weighted Average (Building Projects)	**6.06%**	**17.16%**

CHAPTER III – SCOPE OF STUDY

3.1 Introduction

Risk management has always been an important part of construction projects in order to deliver a project within the contracted budget and schedule parameters. Researchers have investigated in the field of risk management in construction projects, contributing to the risk identification and management of identified risks across the construction projects. In order to extend the existing knowledge on risk management, this study performance a root-cause analysis of individual risk sources, documents the corresponding cost and schedule impact characteristics, and investigates the associated risk management actions taken by the project team (in terms of risk identification, risk mitigation, and risk resolution). This chapter describes the theoretical point of departure, study domain, research questions, the expected research contribution, and research hypotheses.

3.2 Theoretical Point of Departure

The theoretical point of departure for this study was that the literature currently lacks sufficient data measures that quantify individual risk events that are encountered by construction project teams. Whereas much risk management research in the construction industry has analyzed change orders, this study contributes an additional level of detail by studying individual risk events. This additional level of detail is important because a single change order often reflects the combined cost and schedule impacts from multiple risk events; further, many risk events occur during the construction process that do not result in change orders, yet still require substantial risk management effort to be expended by the project team. Consistent with the unit of measure at the level of discrete risk events, the researchers also proposed a new set of risk management timing metrics to systematically document the construction project team's risk identification, risk mitigation, and risk resolution actions. The associated cost and schedule impact of each risk were also captured, along with the root-cause source that triggered each risk to occur.

A related gap in the literature stems from the fact that the risk management actions taken by construction project teams are also largely unquantified. These knowledge gaps within the literature revealed a fundamental need to establish robust units of measure that enable greater in-depth analysis of construction project risk events. To address these literature gaps, this study established a more detailed level of data collection that was specifically focused on individual risk management events that occurred within the construction process. The unit of measure within this study focused on the systematic documentation of each risk event that was encountered on-site and necessitated formal risk management actions by the construction project team. Within this study, a risk event was defined as the discrete instance of any potential deviation from the original construction documents and associated contractual terms and conditions, where the event does – or has the immediate potential to – result in a cost or schedule deviation on the project construction phase.

The existing research in the field of risk management contributed to various findings and answered many questions yet left many unanswered. This thesis commences with the fact that there is a lack of empirical investigation of risk management considering the individual risk source, risk characteristics, and direct impacts of the risks on a construction project. Many previous studies were either focused on risk management/change order management or the impacts of risks/change orders on the project, but lacked to explain the relationship between the identified risks and the change orders on the projects. The main objective of this research is to further explore and explain the gap in risk management understanding the relation between risk source, risk characteristics and impact of risks along with the empirical findings related to the risk characteristics and impacts. This study is mainly focused on finding the relationship between the characteristics of risks (risk identification, risk resolution and risk active duration), distribution of risk across the construction phase and direct impacts of this risks, in terms of cost and schedule, on the project. Compared to the previous researches, the data used in this study was primarily collected from 68 different projects involving different clients, contractors and designers. All the previous studies included variables describing only risk identification timing whereas this study involved other variables related to risk characters namely risk resolution timing and risk active duration along with the impacts on the project. The data analysis was conducted using the descriptive techniques and empirical analytical methods at the individual risk level (risk source, risk characters, impacts) as well as at the project level (peak risk occurrence, change in project budget and schedule).

This thesis starts from the fact that there is a lack of empirical data within the construction risk management literature to describe the occurrence of risk events throughout the construction process. Numerous previous studies have analyzed the construction industry in terms of the magnitude of change orders and overall schedule delays that affect projects, but these studies often do not quantify the impacts of individual change orders and risk factors nor do they typically describe root-causes (Bogus et al. 2013, Cantatelli et al. 2012, Chen et al. 2016, Flyvberg et al. 2003, Hale et al. 2009, Hanna and Gunduz 2004, Konchar and Sanvido 1998, Migliaccio et al. 2008, Odeck 2003, Ojo et al. 2010, Riley 2005, Rosner et al. 2009, Shehu et al. 2014). Other studies have investigated the many risk factors related to change order causes and effects, yet the methodological design of these studies has been predominantly limited to survey-based measurement of practitioner perceptions rather than empirical project data (Alnuaimi et al. 2010, Assaf and Al-Heiji 2006, Chan and Kumaraswamy 1997, Doloi et al. 2011, Frimpong et al. 2003, Gunduz et al. 2013, Hanna et al. 2013, Hsieh et al. 2004, Ndekugri et al, 2008, Rosenfeld 2014, Sambasivan and Soon 2006, Sullivan and Guo 2009). Further studies have investigated the timing, occurrence, and cumulative impact of individual change orders, but do not specifically describe the discrete scope items that comprise each change order, nor do these studies account for risk events that did not result in formal project cost or schedule impacts (Ibbs 2005, Hanna and Swanson 2007, Hanna et al. 1999, Serag et al. 2010, Taylor et al. 2011).

3.3 Study Domain

The research data was collected from 68 completed construction projects. The completed construction projects included new construction projects as well as renovation projects. The project database included projects from two countries:

- 53 construction projects from the United States of America
- 15 construction projects from Canada

The construction projects were all representative of the public sector, including at least one project constructed for owner organizations from the following entities: federal government, military, public utility, state government, county, municipality, public school district, institution of higher learning. All projects represented the vertical sector, and project scopes consisted of both renovations and new construction in the areas of general, mechanical, electrical, civil works, roofing, building envelope, and specialty construction. Projects ranged in value from $103,000 to $25,987,230.

The research domain is further explained; including detailed demographic information of the data sample, in Chapter IV Research Methodology.

3.4 Research Questions

This study was focused on investigating the following research question to answer:

- At the individual risk level, do different risk sources exhibit different characteristics in terms of their frequency, timing and magnitude of cost and schedule impacts?
- At the individual risk level, are there general trends between the risk management actions (risk identification, risk resolution and risk active duration) taken by construction project teams and the impacts of these risks to the project's cost and schedule?
- At the project level, is the risk loading (timing and magnitude) of the project in the construction phase generally related to the overall cost and schedule performance of the project?

3.5 Expected Research Contribution

This study contributes to the construction engineering and management body of knowledge by investigating specific risk management metrics and associated cost and schedule implications. The selected variables will indicate the most common sources of risks within the construction phase, as well as when these risks occur and what their expected impacts are to project cost and schedule. The relationship between these risk metrics and associated risk management actions taken by the project team will form verifiable conclusions about the importance of risk management actions in leading to successful project control. The research will provide valuable information to guide industry practitioners and is expected to motivate more formal risk management collaboration between the project owners, design consultants, and project field contractors.

Another contribution of this study was the establishment of empirical variables to capture dynamics of the risk management actions taken by construction project teams. For each discrete risk event, the point in the schedule at which risk was first formally identified and communicated was recorded, along with the point at which the risk was officially resolved. The interim duration of risk mitigation response taken by the team between these two points in time was also calculated. On this basis, the researchers developed a set of risk management timing metrics (risk identification, risk mitigation, and risk resolution). These measures, taken in conjunction with information on risk root-causes as well as cost and schedule impacts, served to broaden the view of the complexity inherent within the construction process.

This study also contributes to the body of knowledge by investigating the relationship between risk management actions taken by construction project teams and the corresponding cost and schedule performance of the project. The defined variables will indicate when risks occur during construction, what their root-cause source was, and what their ultimate impact to cost and schedule is, if any. This study is meant to produce a set of statistically significant relationships between risk management actions and project cost and schedule changes for design-bid-build vertical sector projects. These relationships will form verifiable conclusions about risk management practices and associated project success criteria, which will be beneficial to guide future industry project teams.

CHAPTER IV - RESEARCH METHODOLOGY

4.1 Introduction

The research method adopted in this study incorporated an analysis documented project management records of completed construction projects. The research results are highly dependent on the quality and comprehensiveness of the project data collected (Sun and Meng 2009). The development of the research database included detailed examination of project management records from more than 100 new construction and renovation construction projects, which then was narrowed down to 68 projects based on the schedule completion status of the projects and data integrity. The research data included data from projects, collected from different clients, occurred from 2008 onwards to 2015. The data collection process involved the use of a special risk management tool referred to as "Weekly Risk Register (WRR)" which required, as the name suggests, weekly update of register for a particular project.

4.2 Data Collection

The data collection tool used to record data, referred to as WRR, was maintained and updated by each contractor's project manager on weekly period. The client project managers were responsible to verify the accuracy and uniformity of the data entered for each project. Data collection included a weekly conference call between the project team that involved client project manager, contractor project manager, design representative, architecture, and the research team members. The contractor's project managers were responsible to lead the conference call every week from the project start date till the project close out date.

4.2.1 Weekly Risk Register (WRR)

The Weekly Risk Register (WRR) is a worksheet developed by the research team with the help of the feedback from the industry participants. The WRR consisted of three main worksheet tabs, namely the Award, Risks & Innovations, and Summary tabs along with two hidden tabs named as Transfer–Project and Transfer–Risks tab. As shown in Appendix A, the Award tab documented the contract information such as the owner name, project number, project title, type of the project, delivery method, client project manager, awarded contractor, contractor project manager, awarded cost, project start date, project end date, duration of the project, etc. The information on the award date was filled at the beginning of the project with the help of the project team to maintain a clear focus on the baseline contracted cost and schedule requirements during the midst of week-to-week project management meetings.

Appendix A shows the Risks and Innovation tab, which was mainly used to record each individual risk that was identified by any of the project team members (regardless of whether it was the client, consultant or contractor). Throughout the construction phase of each project, the Risks and Innovation tab was utilized as a collaborative risk management tool to clearly communicate and track all risk events experienced throughout the project, along with the associated cost and schedule impacts of each individual risk. The risks and innovation tab contained several columns as described below:

- Serial Number (#) denotes the number for each risk entered into the WRR, starting at one and progressing sequentially through 99. If the project encountered more than 99 risks, the WRR was modified by adding rows to the sheet in order to accommodate the additional risk items.

- Date Entered shows the date on which a particular risk was identified and entered in the risk register as mutually agreed upon by the project team members. This date signified the time at which the risk was formally communicated (in the form of written documentation) and acknowledged by all key project stakeholders.
- Source of the Risk/Innovation categorized the source of each individual risk as mutually decided by the project team members. As for the research purpose, the sources of risk are categorized into client, contractor, designer, and unforeseen. These sources are further sub categorized in 10 different categories as shown in Table 4.1. Each cell in this column was independently reviewed and validated by the research team, such that the project team members had to mutually agree upon any one out of the 10 available sources for each risk that was documented within this research study.

Table 4.1 Categories for Source of Risk

Sr. No.	LABEL	SOURCE OF RISK CATAGORIES	DESCRIPTION/DEFINITION OF SOURCE
1	CLSC	CLIENT: Scope Change	Change in original scope work as requested by client
2	CLNS	CLIENT: Non-Scope Change	Risk that require permission , action or resources from the client
3	CLIE	CLIENT: Innovation / Efficiency	Risk generated out of client proposed innovative recommendations to save cost and time
4	CNEO	CONTRACTOR: Error / Omission / General Issues	Risk generating out of contractor error, means/methods, or management on project site
5	CNSS	CONTRACTOR: Sub / Supplier	Issues related to subcontractor or delay in supply of materials
6	CNIE	CONTRACTOR: Innovation / Efficiency	Risk generating out of contractor proposed innovative recommendations to save cost and time
7	DEEO	DESIGNER: Error / Omission	Risk related to design errors or omissions on site during construction phase
8	DEIE	DESIGNER: Innovation / Efficiency	Innovative recommendations to save cost and time from design team
9	UNCC	UNFORESEEN: Concealed Conditions	Risk related to existing or unknown conditions on project site
10	UNUE	UNFORESEEN: Unexpected Events / Weather	Risk due to extreme weather, market fluctuation and all other unforeseen events

- Risk/Innovation Brief Narrative Description included a descriptive information of a particular risk. The descriptive information followed a standard format for each individual risk item, which included a description of what the risk was, what actions the project team was taking to mitigate the risk, which specific members of the project team were responsible for particular risk mitigation deliverables, the potential and actual impacts to project budget, schedule, and quality, and on-going updates as necessary throughout the risk mitigation process.
- Actual Date Resolved documented the date on which a particular risk was completely resolved, as mutually agreed to by all project stakeholders. Within this study, the definition of risk resolution was said to be the point in time at which all parties agreed that the risk was no longer an active issue on the project and all related risk mitigation activities had been completed.
- Schedule Impact captured the impact of each individual risk on the project's contracted schedule. The numerical value of the schedule impact, positive or negative, denotes the number of days added or deducted from the project's contracted schedule. Risk items that did not result in an impact to the contracted schedule were denoted as having zero days of schedule impact. In this manner, the schedule impacts that were documented within this study corresponded to the overall critical path schedule of the project and did not include impacts to float or non-critical path milestones.
- Cost Impact documented the impact of each individual risk on the contracted project cost. The numerical cost impact value, positive or negative, denoted the dollar amount added to or deducted from the project's contracted cost.

- Satisfaction with Contractor's Risk Response was a numerical satisfaction value entered by the client's project manager on a scale of 1 to 10, with 1 being highly unsatisfied and 10 being highly satisfied by the contractor's response on a particular risk. The satisfaction rating was not related to the Owner's surprise or unhappiness with the simple fact that a risk had occurred; rather, the project team was trained that the satisfaction score was specifically focused on the Owner's satisfaction with the contractor's risk management activities, including timely risk identification, honest risk analysis, and prompt risk mitigation activities.
- Institutional Risk Severity was used to evaluate the severity of each risk to the Owner organization's broader operations, with 10 being major institutional impact, 5 being moderate institutional impact, and 1 representing that the risk was limited to having a project level impact.

Appendix A shows the third tab, called the Project Summary tab. As the name suggests, the Summary tab summarized the number of risks based on the source of risk, showed cost and schedule impact associated to each category of risk source, total impact on the project cost and schedule and also the change order rate and schedule delay rate. The calculations on the summary tab were based on automated and standardized formulas entered by the research team; therefore, the project team members were only asked to review the tab for accuracy and were not required to actively enter data on this tab. The information on the summary tab was a combination of the previous Award, and Risks and Innovations tabs, essentially functioning as a project-level summary of all deviations and potential deviations to project cost and schedule as caused by the cumulative impacts of individual risk events. Mathematical formulas were used to calculate useful information such as change in dollar amount of the project cost, change in schedule of the project, change order rate and delay rate on the project, while linking this information to the various risk source categories.

The hidden two tabs, Transfer-Project and Transfer-Risks were not actively utilized by the construction project teams and were solely structured to support research objectives of quickly and accurately transferring data from individual WRR files into a single, compiled database of risk data across all projects within the data sample. The two tabs were hidden, as no direct entry is required by any of the project team members or by the research team due to automatic formulas that were established by the research team at the outset of the research study. The main purpose of these two tabs was to assist in sorting the information collected on other previous tabs. The sorted information is only used by the research team to carry out statistical analysis on the data.

4.2.2 Data Collection Process

The data collection process involved a pre-defined protocol, which included a conference call meeting periodically for each project within the data sample. Within each project, the WRR was updated on a weekly basis for the duration of the construction phase. The contractor's project manager was responsible for updating the written content within the WRR each week and then distributing to the entire project team, including the owner's project manager and the owner's consultant, who were responsible for reviewing the WRR for accuracy, timeliness, and agreement. Other stakeholders were included – such as user groups, procurement officers, site superintendents, subcontractors, and suppliers – as deemed necessary by the project team on a project-by-project basis. Upon updating the WRR each week, the contractor's project manager was required to distribute the document via email to each of the other project stakeholders, along with the researchers, at a mutually agreed-to weekly time.

Along with distributing the WRR via email, each week the entire project team conducted a weekly risk conference call to review the WRR, make necessary adjustments, and take corrective actions as required. Such conference calls typically occurred on the weekday following the agreed-to email submission of the WRR. The contractor's project manager was responsible to lead the conference call, which is joined by the client's project manager, designer team representative, procurement team representative, and the research team members. The conference call mainly involved discussing the recently updated version of WRR in a line-by-line review of the new risks introduced on the project along with any previously identified risks that were still active (not closed out) on the project On average, the duration of conference calls for each project was recorded between 20 minutes to 30 minutes. All participating stakeholders were trained on how to update the WRR, distribute via email, and conduct the weekly risk conference call in a standardized manner for all projects within the dataset.

Once the project was completed, the efforts were made by the owner's project manager to complete and verify the risks entered in terms of source of risk, cost, and schedule impacts, etc. This risk data was also verified by the research team at the end of each project and then transferred to a database spreadsheet. The risks entered had a cost and schedule impact on the project along with the major source that caused the risk to occur. The formal change orders resulting from these risks were also recorded officially on a separate sheet. Often a change order on a project resulted from combination of two or more recorded risks with cost, schedule, or both cost and schedule impacts.

The original database consisted of more than 100 projects, collected using WRR tool. The 100 projects were then narrowed down to final dataset of 68 projects that were used for this study. The determination of the 68 projects was based on certain criteria, 1. Availability of the complete project data, 2. Accuracy of the risk data as determined by the research team, 3. Based on the minimum predetermined awarded cost and schedule duration of the project. The projects that were excluded from the final dataset had incomplete project data such as missing impact values of identified risks, undetermined risk sources, missing identification and resolution dates, etc. Also, the project that had budget and schedule duration less than $100,000 and 30 days were excluded from the final dataset.

4.3 Research Study Data Characteristics

The research data included information on risks and change orders collected from 68 Design-Bid-Build private and public projects across the United States of America and Canada. The procurement method used in these projects were limited to “Low Bid” and “Best Value” Procurement. The project data collected had combination of different clients, contractors and also designers.

The research data were collected from new construction as well as from renovation construction projects. The construction work types (scope of work) were as follows:

- General Construction (46%)
- Mechanical (16%)
- Specialty (13%)
- Electrical (12%)
- Civil Work (Soils/Excavation) (7%)
- Envelope Conservation (3%)
- Roofing (3%)

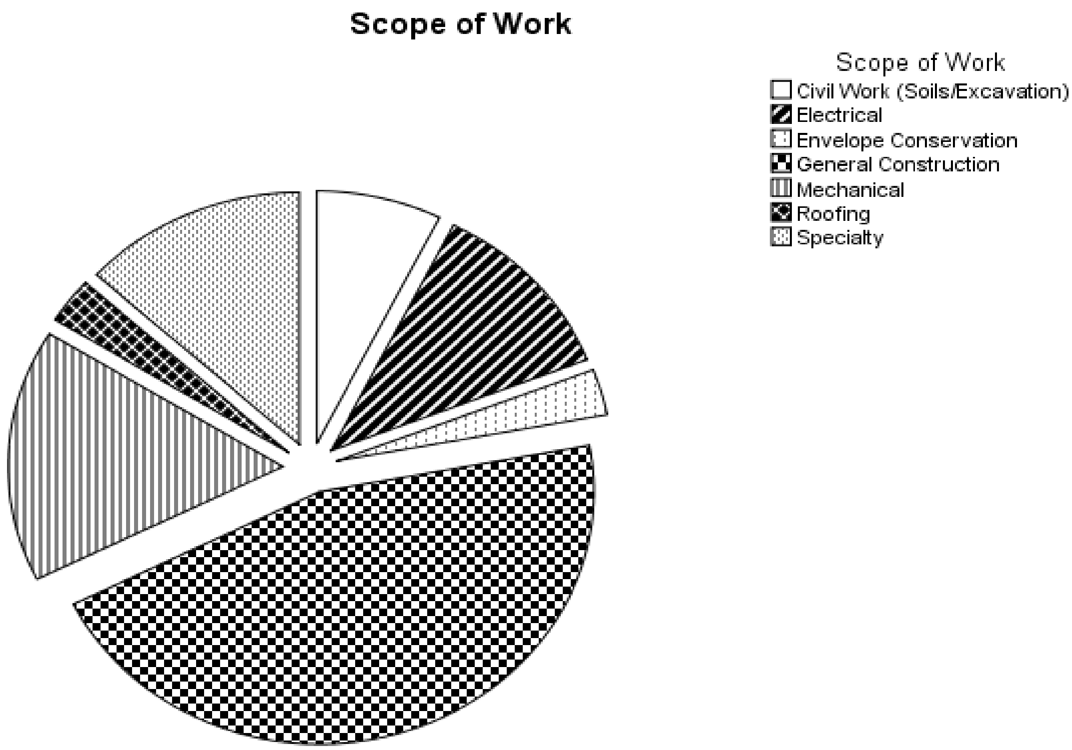

Figure 4.1: Distribution based on Project Type

Table 4.2 shows the summary of 68 collected projects within the dataset. The total awarded cost of projects was $137,486,237, with mean awarded cost of $2,012,856 and a standard deviation of $4,278,689. The total awarded schedule duration of the projects was 13,753 calendar days, with an average of 203 days (approximately 6.5 months) and a standard deviation of 121 days (approximately 4 months). The minimum and maximum of awarded project cost were $103,000 and $25,987,230 and that of project duration were 42 days and 519 days, respectively. The overall cost increase in 68 projects was 4% with an average of 7% per project, whereas the overall schedule increase was 21% with an average of 26% per project.

Table 4.2: Project Data Summary

OVERALL PROJECT DATA		Sum	Percentage
Number of Projects		68	-
COST			
Total Awarded Cost	$	137,486,236.70	-
Mean Awarded Cost	$	2,012,856.42	-
Standard Deviation of Mean Cost	$	4,278,688.53	-
Minimum Awarded Cost	$	103,000.00	-
Maximum Awarded Cost	$	25,987,230.00	-
Total Project Completion Cost	$	143,181,886.00	-
Cost Increase	$	5,695,649.30	4.14%
Mean Cost Increase		-	7.17%
SCHEDULE			
Total Awarded Schedule (Days)		13753	-
Mean Awarded Schedule (Days)		203	-
Standard Deviation of Mean Schedule (Days)		121	-
Minimum Awarded Schedule (Days)		42	-
Maximum Awarded Schedule (Days)		519	-
Total Project Completion Schedule (Days)		16592	-
Schedule Increase (Days)		2839	20.64%
Mean Schedule Increase		-	25.56%

4.4 Data Preparation for Analysis

The objective behind this research study was to understand the occurrence of individual risk events, along with their associated cost and schedule impacts, across the construction phase. Also, the focus of the research was to find the relationship between the timing of risks and the cost and schedule impacts associated with the risks. To do so, after collecting the data from different projects, data analysis was performed using SPSS software with the following variable measures.

4.4.1 Outcome Variables (Dependent Variables)

The research results, as derived from the data analysis, can be used to develop a statistical model to quantify the prospective cost and schedule impact based on the risk characteristics. The outcome variables used in this study are defined below:

- Cost Impact: the dollar amount associated with each of the 1502 risks that occurred across the various projects. This dollar amount in its raw form was used as a dependent variable for this study. The variable has an abbreviation as “CSTImp” which represents the cost impact measured as a dollar amount for a particular risk. Moreover, the dollar amount cost impact of each risk was converted to the percentage cost impact variable. The percentage cost impact variable was calculated using the awarded cost of the project to which a particular risk was associated. The abbreviation of percentage cost impact variable is “PERCstImp” and was calculated using following equation:

$$PERCstImp\ (\%) = \frac{Cost\ Impact\ of\ a\ Particular\ Risk\ (\$)}{Project\ Awarded\ Cost\ (\$)} X100$$

Equation (1)

- Schedule Impact: they number of calendar days of schedule delay associated with each risk was also documented. The impact in terms of days, known as schedule impact and abbreviated as “SCHImp” were considered as dependent variable for this study. Similar to the percentage cost impact, the percentage schedule impact was calculated using the awarded schedule duration of the project to which a particular risk was associated. The following equation was used to calculate the percentage cost impact abbreviated as “PERSchImp”

$$PERSchImp\ (\%) = \frac{Schedule\ impact\ of\ a\ Particular\ risk\ (Days)}{Project\ Awarded\ Schedule\ (Days)} X100$$

Equation (2)

- Cost Overrun: The risks that were identified across a project had cumulative impact on the project cost. Cost overrun is difference between the contracted budget of the project and the actual cost, including cost impacts of risks, at the end of the project. The cost overrun is the percentage increase in the original contracted cost of the project, also commonly known as the overall project change order rate.

$$Cost\ Overrun\ (\%) = \frac{Total\ Cost\ Impact\ (\$)}{Awarded\ Project\ Cost\ (\$)} X100$$

Equation (3)

- Schedule Overrun: The risks that were identified across a project had cumulative impact on the project schedule. Schedule overrun is the difference between the contracted duration of the project and the actual project duration at the completion of project. The schedule overrun is the percentage increase in the original contracted schedule of the project, also commonly known as the overall project delay rate.

$$Schedule\ Overrun\ (\%) = \frac{Total\ Schedule\ Impact\ (Days)}{Awarded\ Schedule\ Duration\ (Days)} X100$$

Equation (4)

4.4.2 Predictor Variables (Independent Variables)

Four predictor variables were measured for each individual risk within the construction projects included in the data sample. In addition to four risk-level variables, an independent variable was also considered to analyze the data at the project level. The five independent variables used in this study are as defined below.-

- Risk Identification: To record the occurrence of risk as related to the project schedule, a variable known as Risk Identification was defined. The abbreviation used for this variable is "RiskID" and has percentage as the unit of measurement. The RiskID was calculated using Eq. (3), which included the date on which risk was entered on the 'Risks and Innovations' tab in the WRR, as well as the project start date and the project schedule duration on 'Award' tab in the WRR. RiskID was considered as a continuous variable.

$$RiskID\ (\%) = \frac{(Risk\ Identified\ Date - Project\ Start\ Date)(Days)}{(Project\ Schedule\ Duration)(Days)} X100$$

Equation (5)

- Risk Resolution: To record the successful resolution of the identified risk as related to the project schedule, a variable known as Risk Resolution was defined. The abbreviation used for this variable is "RiskRS" and has percentage as unit of measurement. The RiskRS was calculated using Eq. (4), which used the date on which the risk was resolved as shown on 'Risks and Innovations' tab, along with the project start date and the project schedule duration as shown on 'Award' tab from the WRR. RiskRS was also considered as a continuous variable.

$$RiskRS\ (\%) = \frac{(Actual\ Risk\ Resolved\ Date - Project\ Start\ Date)(Days)}{(Project\ Schedule\ Duration)(Days)} X100$$

Equation (6)

- Risk Active Duration: The difference between the risk identification and the risk resolution is called active risk duration. The Active risk duration (RiskACT) shows the time period for which a particular risk was open on the project as related to the project schedule duration. During the RiskACT, members of the construction project team were assumed to be engaged in risk mitigation activities as needed to achieve eventual risk resolution. RiskACT has percentage as the unit of measurement and was considered as continuous variable.

$$RiskACT\ (\%) = RiskRS(\%) - RiskID(\%)$$

Equation (7)

- Source of Risk: The identified risk was categorized in to one of the ten listed risk sources in Table 4.1. The source of risk refereed to the root cause responsible for risk's occurrence.

The abbreviation for this variable was “SRCofRSK” and was considered as categorical variable.

- Risk Loading: Risk loading is defined as the open risks that are being actively managed by the project team at a given point in a project schedule. A risk in a construction project is considered to be active until the time it is resolved completely by the project management team. A risk is addressed resolved once the project team successfully mitigates and quantifies the risk in terms of cost and schedule. In order for a risk to be considered fully resolved, the previous information need to be reviewed by the entire project team and verbally agree that the information was accurate and that the risk item was completely resolved. Each identified risks are active on the project schedule depending on the severity of the risk. This brings the necessity to understand the risk loading, which is defined as the number of risks active at a particular point in the project schedule. Thus it becomes more important to know the point in the project schedule where the numbers of active risks are highest. The point in the project schedule at which the numbers of active risks are highest is called the peak risk load. The cost and the schedule overrun of the project are greatly influenced by the timing of peak risk load and magnitude of peak risk load. The timing and magnitude of peak risk load was calculated for 68 individual projects using mathematical expression based in excel spreadsheet. This study included determining the timing and magnitude of peak risk load to understand the trend in cost and schedule overrun in construction projects due to encountered risks.
- Timing of the Peak Risk Loading: To analyze the trend in cost overrun and schedule overrun of the projects, a variable showing the risk peak time on project schedule was calculated. The peak risk time for each of the 68 individual projects was calculated and

analyzed to understand the relation between occurrence of peak risk timing and cost and schedule overrun of the projects. The peak risk time is expressed as percentage in terms of completion of project schedule. Peak risk timing shows a point in the project schedule where maximum numbers of risks are active for the project team to manage compared to any other point in the project schedule.

- Magnitude of the Peak Risk Loading: To analyze the trend in cost overrun and schedule overrun of the projects, a variable showing the number of risks at the peak occurrence in a project schedule was calculated. The peak risk magnitude was calculated for each 68 projects to understand the relationship of the cost and schedule overrun with the number of risks at the peak. Peak risk magnitude shows the number of active risks at the peak occurrence in the project schedule.

4.5 Methods of Analysis

The final dataset consisting of 68 projects was then analyzed using the descriptive statistics and inferential statistics to describe and test the hypotheses, respectively.

4.5.1 Descriptive Statistics

The final dataset consisting of 68 building construction projects were quantitatively expressed using the descriptive statistics analysis. In layman's words, the descriptive statistics was used to summarize and describe the final dataset. The risk and the project level information is expressed in next chapter using descriptive statistics. The descriptive statistics are generally different from inferential statistics as they only describe the dataset used for the study. The descriptive statistics used both, the quantitative (summary tables) and visuals (graphs) to express the data. The descriptive measures used to quantify the risk and project data included measures such as central tendencies (mean, median and mode), variance (standard deviation), along with minimum and maximum values.

4.5.2 Inferential Statistics

The inferential statistical analytical methods were used to test the hypotheses and derive the results to answer the research questions. Following inferential statistical methods were used:

- ANOVA Test: Analysis of variance (ANOVA) is a statistical test used to find the relationship between the means of two or more independent groups. That is, it is used to analyze the difference between the means of two or more independent groups. In order to perform the ANOVA test, following six assumptions are considered-

  Assumption 1 – One of the dependent variable should be a continuous variable,

  Assumption 2 – One of the independent variable should be a categorical variable with two or more categories,

  Assumption 3 – There should have independence of observations,

  Assumption 4 – There should be no significant outliers in the groups of the independent variable in terms of the dependent variable,

  Assumption 5 – The dependent variable should be approximately normally distributed for each group of the independent variable.

  Assumption 6 – There should be homogeneity of variance.

  The ANOVA results are expressed in a table consisting of significance value (p-value), df (degrees of freedom), and F value. The most important part of the result is the significance value. The significance value smaller than 0.05 shows that the difference between the means of the groups is statistically significant. The F value is the value that denotes the F statistic obtained by division of variance between groups by the variance within the groups.

For this study, the ANOVA test was performed to know whether the cost and the schedule impact of the identified risks differs based on the risk management actions (risk identification, risk resolution and risk active duration).

- Linear Regression: The statistical linear regression method is used to find the relationship between the dependent variable and the independent variable. Along with assessing the relationship between the variables, it also predicts the value of a dependent variable based on the value of an independent variable. The linear regression is based on seven assumptions showing how well the data fits the regression model. The following seven assumptions are considered:

  Assumption 1 - One dependent variable should be a continuous variable,

  Assumption 2 - One independent variable should be a continuous variable,

  Assumption 3 – The dependent variable and independent variable should be linearly related,

  Assumption 4 – The data should show independence of observations,

  Assumption 5 – The data should not have significant outliers,

  Assumption 6 – The data should show homoscedasticity,

  Assumption 7 – The data should be normally distributed.

  The linear regression results shows the slope coefficients value and intercept value to predict the dependent variable value. The results also includes the significance value (p-value) and the coefficient of determination (R-squared value) to check the statistical significance of the model and measure how close the data are to the regression model, respectively. The slope coefficient can be negative as well as positive value. The negative slope coefficient value shows the negative (inverse) relation between the dependent variable and independent variable whereas, the positive slope coefficient value shows the positive relation (direct) between the dependent and independent variable. The p-value smaller than 0.05 shows that the regression model is statistically significant which also means that there exists a linear relationship between the variables. The coefficient of determination can be from 0% to 100% where a value close to 0% shows that the model explains none of the variability of the response data around its mean whereas, a value close to 100% shows that the model explains all the variability of the response data around its mean. Often the linear regression results are complemented by displaying a graph such as scatterplot, boxplot, etc.

For this study, the linear regression was carried out to understand and find the relation between risk management actions and the cost and schedule impact of the identified risks. In addition to this, the linear regression was also conducted at the project level to understand the relationship of cost and schedule overrun with the timing of peak occurrence and number of risks active at the peak. The linear regression results are explained in next chapter.

- Multiple Regression: Multiple regression is the extension of the linear regression, which includes finding the relation between dependent variable and two or more independent variable. The empirical model developed using the multiple regression, predicts the dependent variable based on two or more independent variables. The assumptions for multiple regression analysis are same as the linear regression analysis assumptions. The results of the multiple regression are also interpreted in a way similar to that of a linear regression results.

For this study, the multiple regression was conducted at the risk level to understand the relation and develop an empirical model of cost and schedule impact based on the risk identification timing, risk resolution timing and risk active duration timing. The multiple regression results are described in the next chapter.

CHAPTER VI - DATA ANALYSIS

5.1 Introduction

The main aim of the study was to understand the relationship between the cost and schedule impacts of construction project risks based on the timing of the project team's risk management actions, specifically related to the timing of risk identification, risk resolution, and duration of risk mitigation activities. In order to determine this, descriptive and statistical methods of data analysis were performed. The analysis included 1502 risks that occurred across 68 construction projects. A descriptive analysis was performed on the data variables to determine the cost impact, schedule impact, risk identified mean, risk resolved mean, and risk active duration mean associated with the ten risk categories. In addition to descriptive analysis, inferential statistical analysis included linear regression, multiple regression, data normalization, and the parametric ANOVA test. Also, the data at project level was descriptively and inferentially analyzed to understand the association between risk management actions and project-level cost and schedule overruns across the 68 projects.

5.2 Descriptive Analysis

The descriptive analysis was performed at the risk as well as the project level. The analysis at the risk level was based on the risk categories, risk distribution, magnitude of the cost and schedule impact along with the analysis at project level.

5.2.1 Risks by Category

Figure 5.1 shows the distribution of risks based on the risk categories across the study data. It is clear from the figure that the client scope change and designer error/omission are the most common reasons for the risks encountered across the projects, followed by unforeseen concealed conditions.

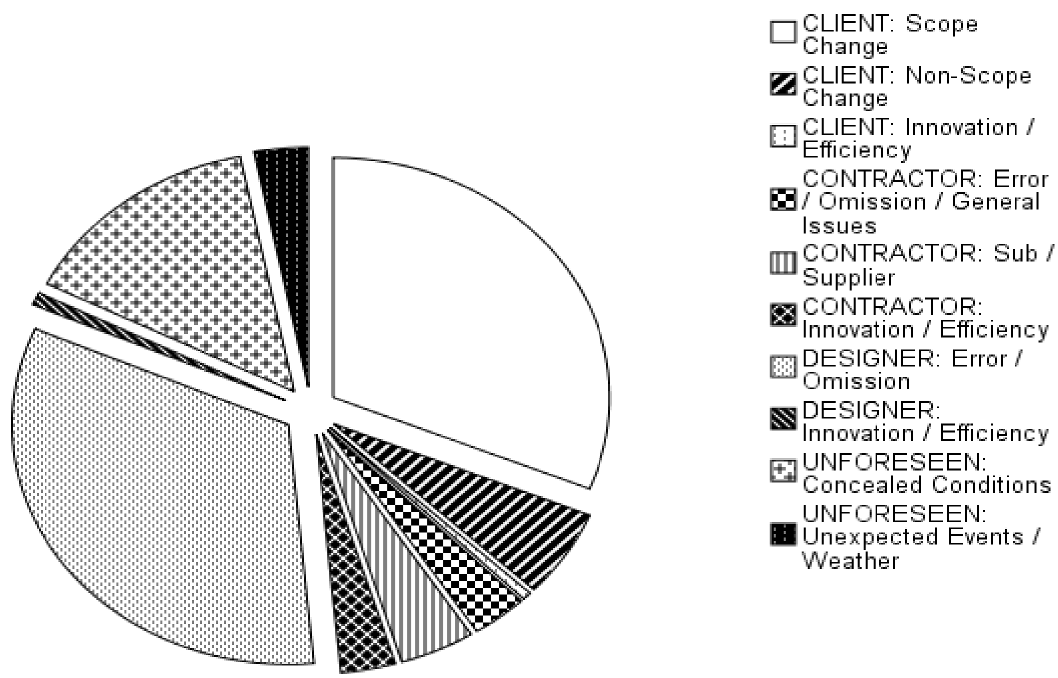

Figure 5.1: Risk Distribution Based on Risk Source

Table 5.1 shows the descriptive analysis of cost and schedule impacts associated with the risk categories along with the frequency of risks based on the risk source. Risks that occurred on the projects were associated to one of the ten categories and based on that, the highest number of risks (496) occurred were due to the designer team error and omissions on the project. This was followed by 469 risks that occurred due to client scope change, 89 risks resulting from client non-scope changes, 217 risks resulting from unforeseen concealed conditions, and 47 risks resulting from unforeseen events on the projects. The risks resulting from contractor error and omissions were only 49 as compared to the 66 risks resulting from sub-contractor and suppliers delays. Client innovation and efficiency, contractor innovation and efficiency, and designer innovation and efficiency resulted into cost and schedule savings as represented by the occurrence of 8, 48, and 13 risks, respectively. The risks from client scope change had the highest cost and schedule impact of $2,640,414 and 642 days, respectively, followed by cost impact of $1,919,753 and 407 days of schedule impact resulting risks from design error and omissions. The risks resulting from client non scope change had a considerably large schedule impact of 560 days with cost impact of $104,298. Delays from the sub-contractors and the suppliers resulted in additional 356 days to complete the 68 projects. The cost and schedule savings from innovation and efficiency of client, contractor and designer were $43,527, $231,870, and $5,729 with 0, 10, and 28 days, respectively. A significant cost and schedule impact of $1,057,798 and 284 days and $135,319 and 422 days was recorded from unforeseen existing site conditions and unexpected events, respectively.

Table 5.2 shows the descriptive results of the risk identification, risk resolution, and risk active duration related to the ten risk source categories. The results show the means for risk identification, risk resolution and risk active duration which is the average time at which the risk was introduced to the project, average time at which the risk was resolved from the project and the average active duration of a particular risk corresponding to a risk category. In addition to means, the table also shows the standard error, standard deviation, and both the minimum and maximum timing of identification, resolution and active duration for each risk category.

Table 5.1: Descriptive Statistics of Risk Categories

	Risks		Cost Impact		Schedule Impact	
Category	**Count**	**Percentage**	**$**	**%**	**Days**	**%**
CLSC	469	31.23%	$ 2,640,413.71	46.63%	642	22.38%
CLNS	89	5.93%	$ 104,297.90	1.84%	560	19.52%
CLIE	8	0.53%	$ (43,527.00)	-0.77%	0	0.00%
CNEO	49	3.26%	$ 86,217.56	1.52%	236	8.23%
CNSS	66	4.39%	$ 293.86	0.01%	356	12.41%
CNIE	48	3.20%	$ (231,870.05)	-4.09%	-10	-0.35%
DEEO	496	33.02%	$ 1,919,753.04	33.90%	407	14.19%
DEIE	13	0.87%	$ (5,729.42)	-0.10%	-28	-0.98%
UNCC	217	14.45%	$ 1,057,798.55	18.68%	284	9.90%
UNUE	47	3.13%	$ 135,319.00	2.39%	422	14.71%
Total	1502	100.00%	$ 5,662,967.15	100.00%	2869	100.00%

Table 5.2: Descriptive Statistics of the Timing of Risk Management Actions by Risk Category

	Risk Identification					Risk Resolution					Risk Active Duration				
Category	**M**	**SE**	**SD**	**MIN**	**MAX**	**M**	**SE**	**SD**	**MIN**	**MAX**	**M**	**SE**	**SD**	**MIN**	**MAX**
CLSC	0.72	0.02	0.43	0.00	2.96	0.84	0.02	0.45	0.05	3.14	0.12	0.01	0.18	0.00	0.89
CLNS	0.46	0.05	0.44	0.00	2.01	0.65	0.05	0.46	0.00	2.43	0.18	0.03	0.31	0.00	2.29
CLIE	0.65	0.12	0.35	0.19	1.02	0.67	0.12	0.36	0.22	1.07	0.02	0.01	0.02	0.00	0.05
CNEO	0.57	0.06	0.41	0.00	1.38	0.73	0.06	0.42	0.05	1.62	0.16	0.03	0.21	0.00	0.89
CNSS	0.79	0.05	0.41	0.01	2.13	0.95	0.06	0.47	0.01	3.14	0.16	0.03	0.25	0.00	1.46
CNIE	0.57	0.04	0.29	0.00	2.32	0.69	0.08	0.57	0.00	2.52	0.12	0.05	0.33	0.00	1.68
DEEO	0.64	0.02	0.38	0.01	1.85	0.78	0.02	0.40	0.01	2.47	0.14	0.01	0.22	0.00	1.68
DEIE	0.46	0.05	0.19	0.22	0.72	0.52	0.06	0.23	0.23	0.85	0.06	0.03	0.09	0.00	0.25
UNCC	0.58	0.03	0.43	0.00	3.12	0.76	0.03	0.47	0.00	3.66	0.18	0.01	0.23	0.00	1.13
UNUE	0.80	0.14	0.94	0.00	3.97	1.01	0.14	0.94	0.20	4.02	0.21	0.06	0.40	0.00	2.64

Note: M = Mean; SE = Standard Error; SD = Standard Deviation; MIN = Minimum;
MAX = Maximum

Figure 5.2 shows the means of risk identification, risk resolution and risk active duration based on the source of risk. The mean denotes the average time at which the risks were identified, resolved, and average risk active duration as compared to the original project schedule at time of contract award. For instance, on average, the client non-scope and designer innovation/efficiency risks were identified earliest, at 0.46 (46%) in the original project schedule. Conversely, the risks caused by the contractor sub/supplier and unexpected events were identified, on average, later in the project at 0.79 (79%) and 0.80 (80%) respectively. Similarly, the designer innovation/efficiency risks were resolved, on average, early in the project schedule at 0.52 (52%), whereas unexpected event risks were resolved on average later in the project schedule at 1.01 (101%). Moreover, the risks from client innovation/efficiency were active, on average, for the least amount of time that is 0.02 (2%) of the project schedule whereas the risks from unexpected events were open, on average, for 0.21 (21%) of the project schedule.

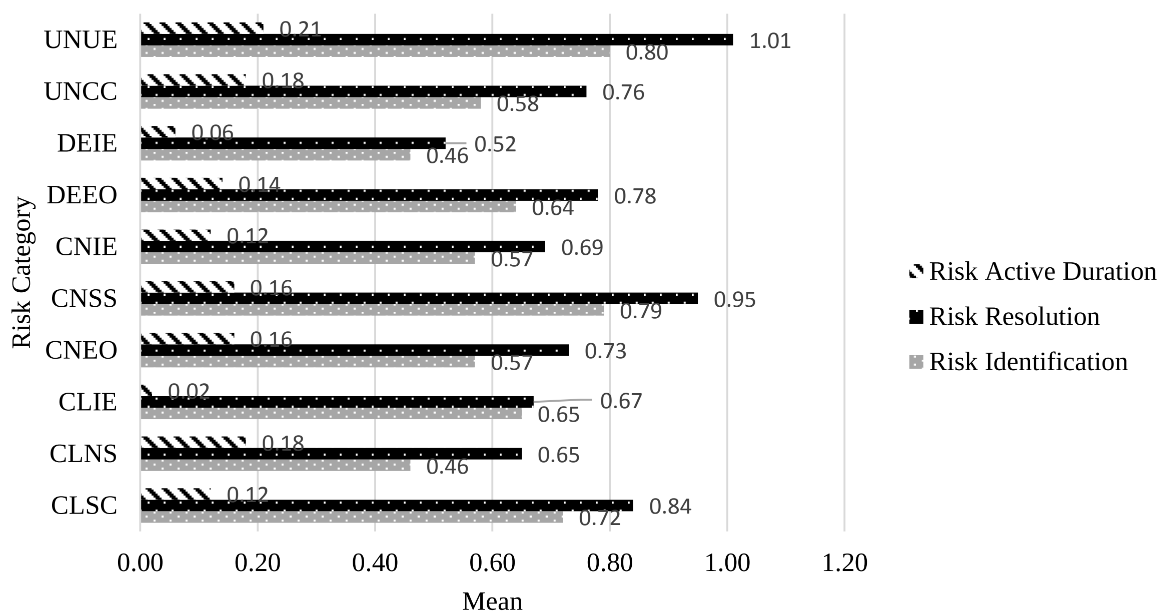

Figure 5.2: Risk Identification, Resolution and Active Duration Mean by Risk Category

5.2.2 Risk Distribution

Figure 5.3 shows the risk identification distributed across the original project schedule. The data shown in the figure includes data from all the 68 projects considered for the research. The profile shows that the risks were identified beyond the original contracted schedule (100%). However, most of the risks (82%) were identified before the original completion schedule and remaining 18% of the risks were identified after the original contracted schedule. The risk identification profile shows multiple peaks during the project schedule. For instance, the risk identification peaks occurred at 20%, 60% and 70% completion of the projects. This means that, more risks are identified by the project team during the early phase of construction and right after halfway through the project schedule.

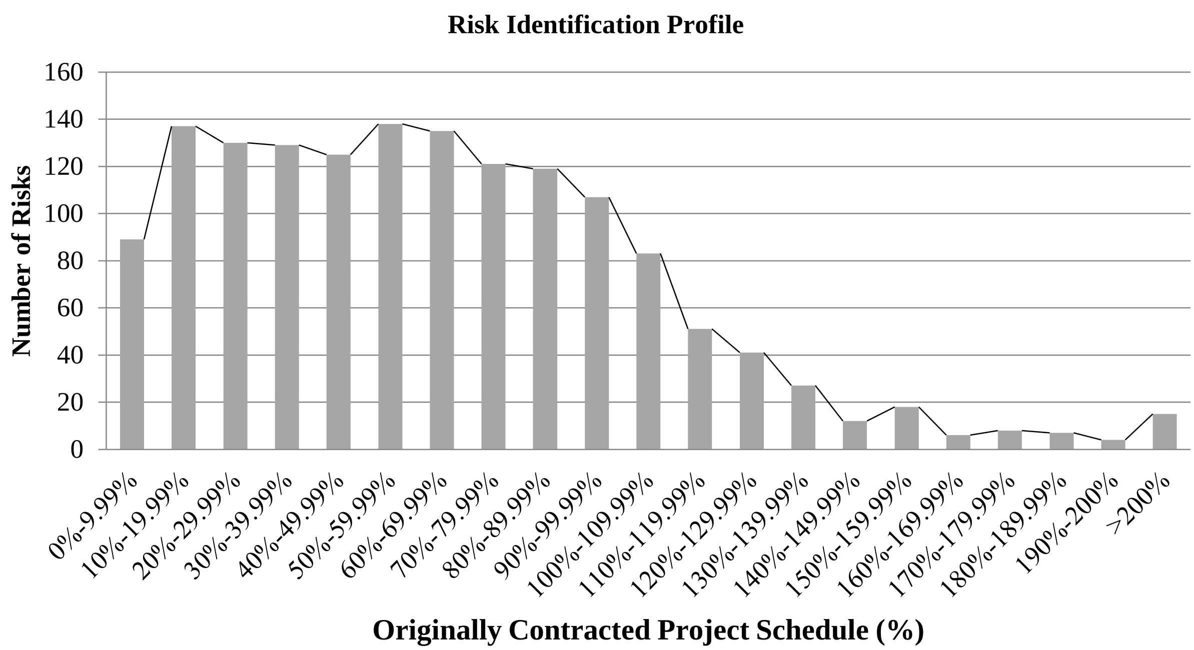

Figure 5.3: Risk Identification Profile

Similarly, Figure 5.4 shows the risk resolution profile across the original project schedule. The profile shows that 72% of the risks were resolved before the original contracted project schedule; however, the remaining 28% of risks were resolved after the original contracted schedule resulting in a delayed project completion. The profile shows that the risk resolution peak occurred at 80%-90%, which is shortly prior to the original project completion schedule.

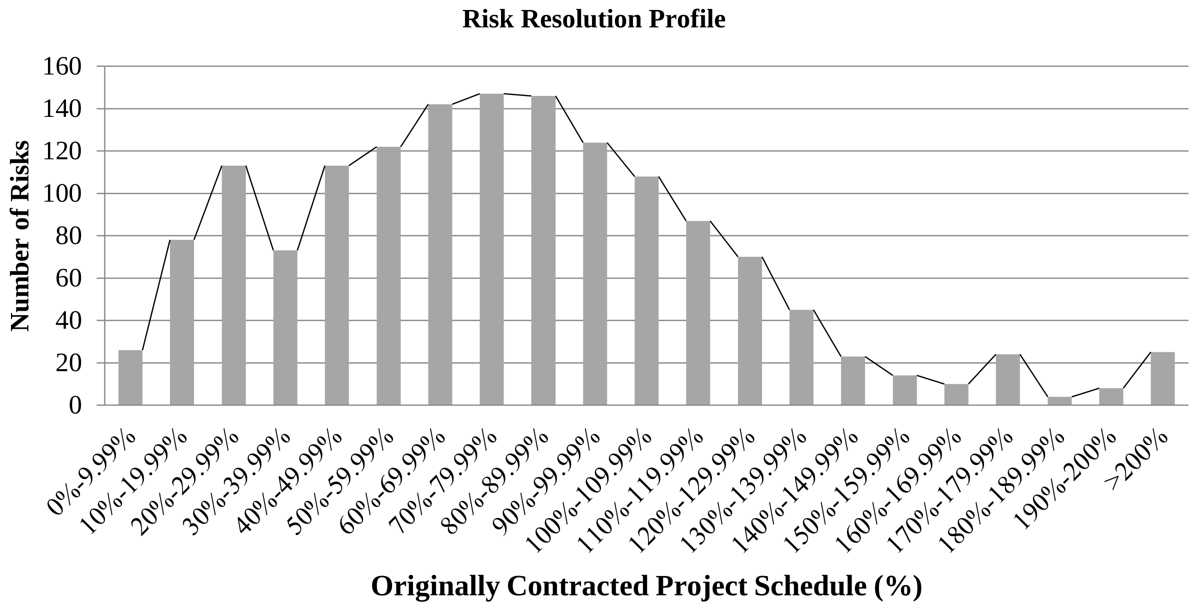

Figure 5.4: Risk Resolution Profile

5.2.3 Risks by Magnitude of Cost Impact

The cost impacts associated with the risks were categorized in to ten groups by the method of sequential doubling the class intervals (Perrenoud *et. al* 2015). Table 5.3 shows the frequency of risks and average identification, resolution, and active duration measures associated with the ten sequentially doubled groupings of risks based upon cost impact. The table shows that 35% of the risks had zero cost impact, 8% of the risks resulted in cost saving on the projects, and the remaining 57% of risks were responsible for an increase in the contracted project budget. It can be inferred from the table that the risks with low cost impacts are occur more frequently compared to the risks with larger cost impacts. Also the major cost impacts on the project budget, are because of the risks with higher magnitude of dollar impact and comparatively lower due to the risks with lower magnitude of dollar impact. Moreover, the risks with higher cost impacts are identified and resolved earlier in the project and had higher active duration compared to the low dollar impact risks.

Table 5.3 Risks by Magnitude of Cost Impact

Magnitude of Cost Impact ($)	Risks					Cost Impact		Schedule Impact	
	Count	Percentage	Average Identification	Average Resolution	Average Active Duration	$	%	Days	%
<$0	119	8%	62%	72%	10%	-$1,164,702.99	-21%	-6	0%
$0	524	35%	54%	71%	17%	$0.00	0%	1772	62%
$1-$1,000	201	13%	77%	88%	11%	$111,009.72	2%	65	2%
$1,001-$2,000	177	12%	76%	88%	12%	$258,560.55	5%	93	3%
$2,001-$4,000	150	10%	75%	90%	15%	$437,958.09	8%	120	4%
$4,001-$8,000	133	9%	66%	81%	15%	$766,902.89	14%	231	8%
$8,001-$16,000	104	7%	71%	86%	15%	$1,170,383.66	21%	137	5%
$16,001-$32,000	44	3%	63%	80%	17%	$954,554.69	17%	88	3%
$32,001-$64,000	32	2%	68%	89%	21%	$1,478,559.64	26%	188	7%
$64,001-$250,000	18	1%	69%	83%	14%	$1,649,740.90	29%	181	6%
TOTAL	**1502**					**$5,662,967.15**		**2869**	

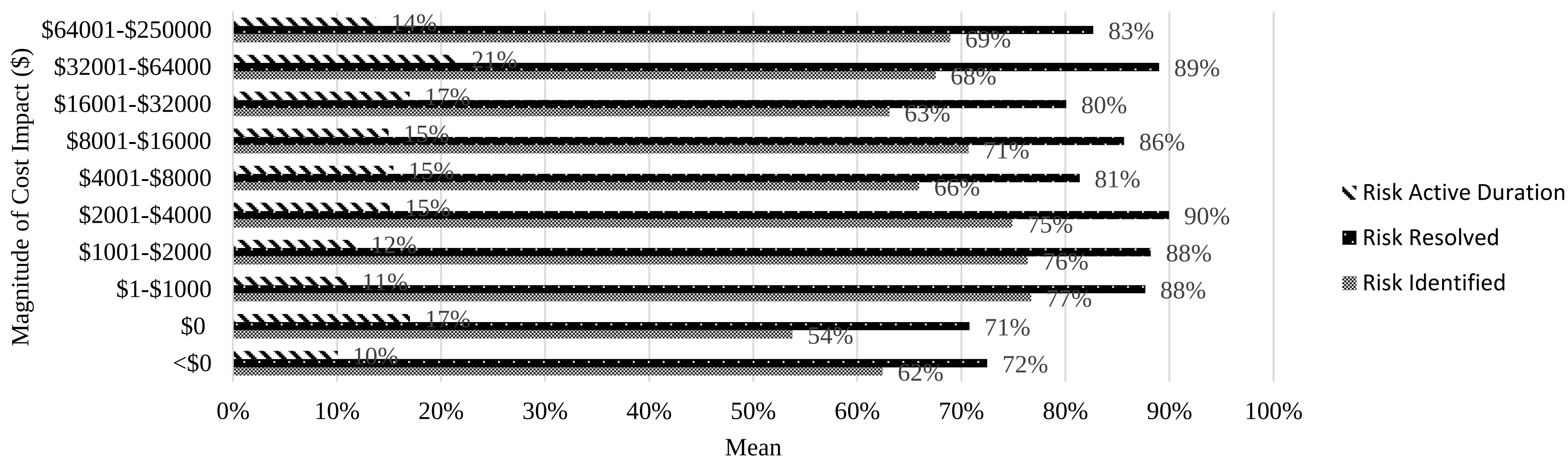

Figure 5.5: Risk Management Timing Means by Magnitude of Cost Impact

Figure 5.5 shows the average risk identification, resolution, and active duration corresponding to the ten groupings of cost impacts. The figure shows that the risks with higher cost impacts were identified earlier, on average, at 63%-69% as compared to risks with lower dollar impacts, which were identified later, on average, at 71%-77% of the project schedule. Also, the risks with higher cost impact magnitude were open longer, on average for about 17%-21% of the project schedule whereas the risks with lower dollar impact were active, on average, for 11%-15% of the project schedule.

5.2.4 Risks by Magnitude of Schedule Impact

The schedule impacts (days) associated with the risks were categorized into nine groups by using the method of sequential doubling of the class intervals. Tables 5.4 shows the frequency of risks and mean identification, resolution, and active duration associated with the nine groups of schedule impacts. The table shows that 89% of the risks had zero impact on the project schedule and a little less than 1% of risks resulted in saving the project schedule (reduction of the critical path schedule). The remaining 10% of risks increased the original contracted project duration. It can be inferred from the table that the risks with higher schedule impacts are occurred less frequently compared to the risks with lower schedule impacts.

Figure 5.6 shows the mean identification, resolution and active duration associated with the nine schedule impact groups. The figure shows that the risks with higher schedule impacts are identified; on average at high risk identified mean (105%-128%) which means the risks that are identified later has higher schedule impact. On the other hand, the risks with lower schedule impact are identified earlier in the project, on average at 54%-75% of the project schedule. Moreover, the risks with higher schedule impacts are active for longer period, on average, for 23%-82% of the project schedule whereas the risks with lower schedule impact are active, on average, for lesser period at 9%-20% of the project schedule.

Table 5.4. Risks by Magnitude of Schedule Impact

Magnitude of Schedule Impact (Days)	Risks					Cost Impact		Schedule Impact	
	Count	Percentage	Average Identification	Average Resolution	Average Active Duration	$	%	Days	%
<0 days	6	0%	73%	77%	4%	-$6,677.07	0%	-102	-4%
0 days	1339	89%	62%	76%	14%	$4,310,060.52	76%	0	0%
1 day-2 days	35	2%	87%	107%	20%	$107,845.50	2%	46	2%
3 days - 4 days	13	1%	50%	59%	9%	$122,325.00	2%	44	2%
5 days - 8 days	40	3%	85%	99%	13%	$286,426.04	5%	243	8%
9 days - 16 days	23	2%	83%	101%	18%	$191,655.42	3%	267	9%
17 days - 32 days	26	2%	105%	128%	22%	$326,024.62	6%	702	24%
33 days - 64 days	12	1%	128%	150%	23%	$256,182.12	5%	505	18%
65 days - 500 days	8	1%	81%	162%	82%	$69,125.00	1%	1164	41%
TOTAL	**1502**					**$5,662,967.15**		**2869**	

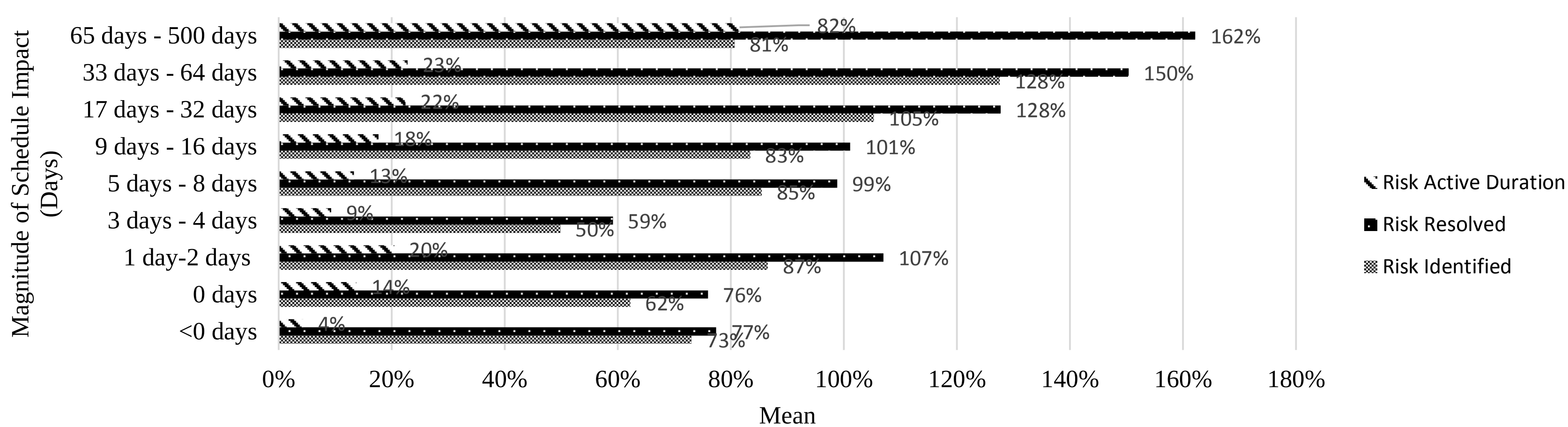

Figure 5.6: Risk Management Timing Means by Magnitude of Schedule Impact

5.2.5 Project Level

Figure 5.7 shows the risk loading profile, which includes all 1502 individual risks from 68 projects. The risk loading profile was calculated using the mathematical equation in excel spreadsheet, considering the greater than x and smaller than y concept to find the number of risks at a particular point in a project schedule, where x and y denotes the risk identification timing and risk resolution timing, respectively. As shown in the figure, a large number of risks were active a little after halfway through the project schedule. On average, the peak risk loading time was identified at 63% of the original project completion schedule, which means that the project team had to manage the maximum number of risks at approximately 50% percent completion of the project.

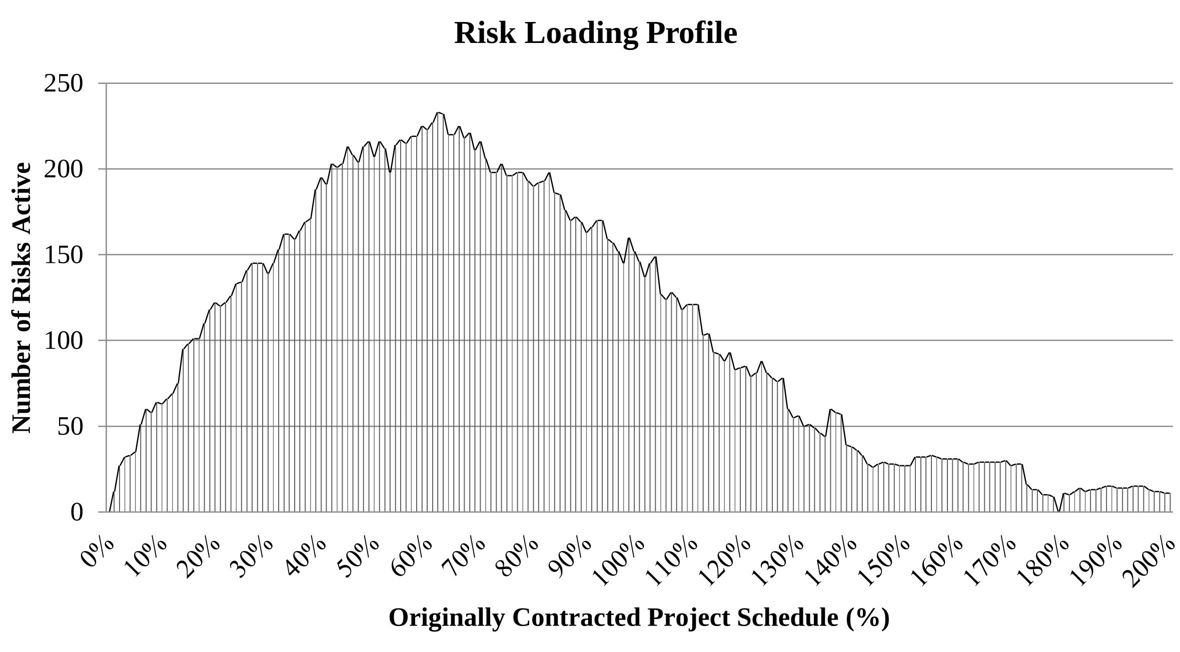

Figure 5.7: Risk Loading Profile

5.3 Linear Regression Analysis

The data collected regarding the individual risks having cost and schedule impacts of values greater than zero were analyzed using linear regression. The linear regression analysis was performed to understand the relationship between the timing of risk management actions (measured as risk identification, risk resolution, and risk active duration) and the cost and schedule impacts of individual risks.

The linear regression included cost impact and schedule impact separately as the dependent variables, in terms of actual dollar and number of days delayed as the units of measure, as well as the corresponding cost and schedule percent increases as a percentage of the total awarded values. The independent variables were risk identification, risk resolution, and risk active duration. Appendix C shows the results of 180 regressions performed as a part of the research. The regression was performed including 1502 risks cases as shown in Table 5.5. A step further, the cases were narrowed down based on the risks depending on ten different categories of risks source and also on four major risk categories, namely client, contractor, designer and unforeseen conditions.

Table 5.5: Regression Results

Sr. No.	Independent Variable	Dependent Variable	R Square	F	P
1	Risk ID	Cost Impact ($)	0.001	1.521	0.218
2	Risk ID	Cost Impact (%)	0.000	0.065	0.799
3	Risk ID	Schedule (Days)	0.008	12.767	0.000
4	Risk ID	Schedule (%)	0.002	2.848	0.092
5	Risk RS	Cost Impact ($)	0.001	1.934	0.165
6	Risk RS	Cost Impact (%)	0.000	0.668	0.414
7	Risk RS	Schedule (Days)	0.051	80.68	0.000
8	Risk RS	Schedule (%)	0.046	71.618	0.000
9	Risk Act	Cost Impact ($)	0.000	0.205	0.651
10	Risk Act	Cost Impact (%)	0.003	4.799	0.029
11	Risk Act	Schedule (Days)	0.082	133.97	0.000
12	Risk Act	Schedule (%)	0.126	216.879	0.000

Linear regression results showed minor significant relationships between the variables. For instance, the regression analysis between risk identification, risk resolution, and risk active duration with the schedule impact shows significant relation for overall 1502 individual risk cases. In addition to this, the schedule impact had significant relationships, as shown Appendix C, to the risk identification, risk resolution and risk active duration when the cases are narrowed down based on the ten risk categories. However, the regression results showed that the cost impacts are not significantly dependent on the predictor variables. The regression results showed positive relationships between schedule impact and risk identification, risk resolution, and risk active duration. This result implied that the later the risks are identified and resolved on a project, and the longer they are being actively managed, the overall project schedule will have a larger higher schedule impact.

5.4 Multiple Regression Analysis

Multiple regression analysis was performed to understand the relationship between dependent and predictor variables and to develop a statistical model to predict the dependent variables. Tables 5.6 and 5.7 presents the results from the multiple regression analysis, which showed the cost and schedule impacts of the risks are related to some extent with the risk identification, risk resolution, and risk active duration timing. The multiple regression model statistically significantly predicted schedule impact, $F\ (2, 1499)$ = 83.703, $p < 0.0005, R^2 = 0.10$ as shown in Table 5.7.

The independent variables, risk identification, risk resolution and risk active duration taken in to consideration for multiple regression showed the presence of multicollinearity and hence only two independent variables were considered to predict the dependent variable. The cost impact was not predicted significantly but the schedule impact showed a positive relationship with risk identification and risk active duration. This result appears to indicate that the later the risks are identified, the greater the corresponding schedule impact will be. Also, the longer was the risk open for the project team, the greater was the schedule impact.

Table 5.6: Multiple Regression Predicting Cost Impact

Items	B	*t-value*	*SE*	*P*
(Constant)	2848.27	3.69	770.86	0.000
Controls				
Risk ID	11.68	1.31	8.88	0.189
Risk RS	Excluded Variable			
Risk ACT	1120.14	0.64	1742.80	0.520
F				0.967
R^2				0.001
N				1,502

Note. B= unstandardized regression coefficients. *SE* = standard error.

Table 5.7: Multiple Regression Predicting Schedule Impact

Items	B	*t-value*	*SE*	*P*
(Constant)	-3.12	-5.09	0.61	0.000
Controls				
Risk ID	0.04	5.55	0.01	0.000
Risk RS	Excluded Variable			
Risk ACT	17.14	12.38	1.38	0.000
F				83.69
R^2				0.10
N				1502

Note. B= unstandardized regression coefficients. *SE* = standard error.

5.5 ANOVA Test

The parametric one way ANOVA test was used to further investigate the relationship between the impacts (cost and schedule) associated with the individual risks and risk management timing of risk identification, risk resolution, and risk active duration values. The ANOVA test is based on the six assumptions, which included data being normally distributed and has homogeneity of variance (variance is equal in each group of the independent variable). The data was checked for normality using the Shapiro-wilk test and the results showed non-normality. As the risk data used for the research showed non-normality the risk data was recoded in to seven groups based on the risk identification, risk resolution and risk active duration. Table 5.8, 5.9 and 5.10 shows the seven groups recoded based on the risk identification, risk resolution and risk active duration respectively.

Table 5.8: Risk Identification Recoded Groups

Group	From	To	Risk Count
1	0	0.19	215
2	0.19	0.35	215
3	0.35	0.52	215
4	0.52	0.68	215
5	0.68	0.85	215
6	0.86	1.06	215
7	1.06	3.98	212
Total			1502

Table 5.9: Risk Resolution Recoded Groups

Group	From	To	Risk Count
1	0	0.30	215
2	0.30	0.52	215
3	0.52	0.68	215
4	0.69	0.85	215
5	0.85	0.99	215
6	0.99	1.22	215
7	1.22	4.02	212
Total			1502

Table 5.10: Risk Active Duration Recoded Groups

Group	From	To	Risk Count
1	0	0	215
2	0	0.01	215
3	0.01	0.04	215
4	0.04	0.08	215
5	0.08	0.16	215
6	0.16	0.32	215
7	0.32	2.64	212
Total			1502

ANOVA was performed using the recoded groups based on risk characteristics and impacts of risks. Using statistical analytical software SPPS, six ANOVA tests were performed between Cost Impact and Recoded Risk Identification Groups, Schedule Impact and Recoded Risk

Identification Groups, Cost Impact and Recoded Risk Resolution Groups, Schedule Impact and Recoded Risk Resolution Groups, Cost Impact and Recoded Active Risk Duration Groups, and Schedule Impact and Recoded Risk Active Duration Groups. The ANOVA results, as presented in Table 5.11, showed that the relationship between the recoded groups and schedule impact were significant, whereas for cost impact and recoded groups the relationship was not quite significant. However, the measure of association (Eta) for each ANOVA results shows negligible strength even for the significant results between schedule impact and the recoded groups.

Table 5.11: ANOVA Test Results

ANOVA				
Factor	**df**	**F**	**Eta**	**p**
Cost Impact and Recoded Risk Identification Groups	6	1.775	0.084	0.101
Schedule Impact and Recoded Risk Identification Groups	6	5.778	0.151	0.000
Cost Impact and Recoded Risk Resolution Groups	6	1.556	0.079	0.156
Schedule Impact and Recoded Risk Resolution Groups	6	9.204	0.189	0.000
Cost Impact and Recoded Active Risk Duration Groups	6	1.071	0.065	0.377
Schedule Impact and Recoded Active Risk Duration Groups	6	2.300	0.096	0.033

5.6 Cost Impact Analysis

To further understand the relationship between cost impact of risks and risk management timing (risk identification, risk resolution, and risk active duration), additional regression analysis using the normalized data was performed. The regression was performed using the normalized cost groups as presented in Table 5.12 and the recoded groups of risk identification, risk resolution and risk active duration, as presented in Tables 5.8, 5.9 and 5.10 respectively. Table 5.12 shows the average recoded timing for risk identification, risk resolution, and risk active duration groups associated with each sequentially doubled cost group. Regression analysis was performed using the normalized data and the risks that had positive non-zero impacts on the project cost.

Figure 5.8 shows the regression plot of cost impact as the dependent variable and average recoded risk identification group as the independent variable. The regression analysis established that the risk identification statistically significantly predicted the cost impact of the risk. As shown in the Figure 5.8, the negative trend line between the cost impact and risk identification indicated that risks identified earlier in the project tend to have greater cost impacts compared to risks that identified later in the project.

Table 5.12: Recoded Risk Characteristic Mean by Cost Impact

Magnitude of Cost Impact ($)	Count	Average		
		Risk Identification	Risk Resolution	Risk Active Duration
<$0	119	3.85	3.67	3.13
$0	524	3.32	3.5	4.23
$1-$1,000	201	4.66	4.53	3.71
$1,001-$2,000	177	4.64	4.38	3.88
$2,001-$4,000	150	4.55	4.45	4.19
$4,001-$8,000	133	4.08	4.12	3.99
$8,001-$16,000	104	4.26	4.24	3.99
$16,001-$32,000	44	4	4.05	4.14
$32,001-$64,000	32	4.13	4.31	4.28
$64,001-$250,000	18	3.61	3.61	4.56
TOTAL	1502			

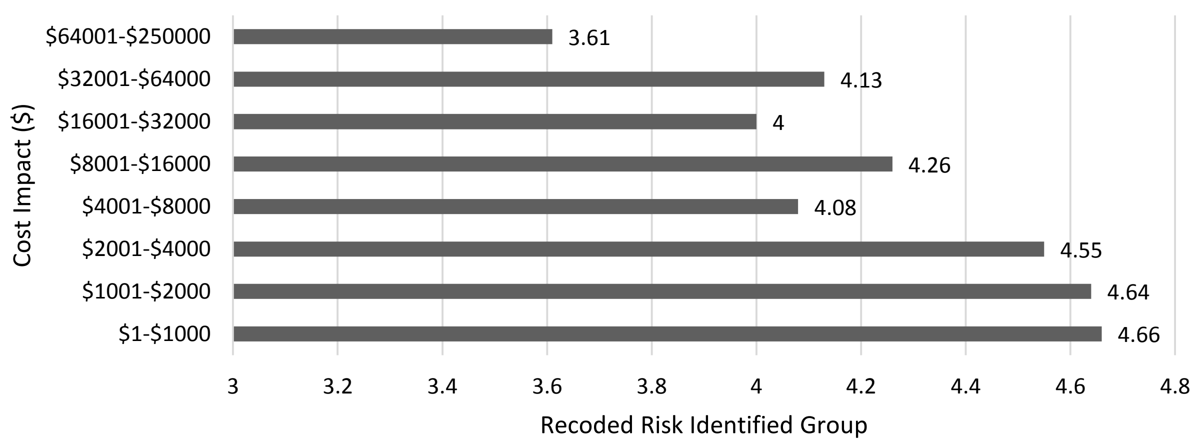

Figure 5.8: Recoded Risk Identification and Cost Impact Groups

Figure 5.9 shows the regression plot of cost impact as the dependent variable and average risk resolution group as the independent variable. The regression analysis established that the risk resolution can statistically significantly predict the cost impact of the risk. The significance and the proportion of variance was equal to 0.0201 (<0.05) and 0.62 respectively. The regression plot shows a negative relation between the cost impact and risk resolution.

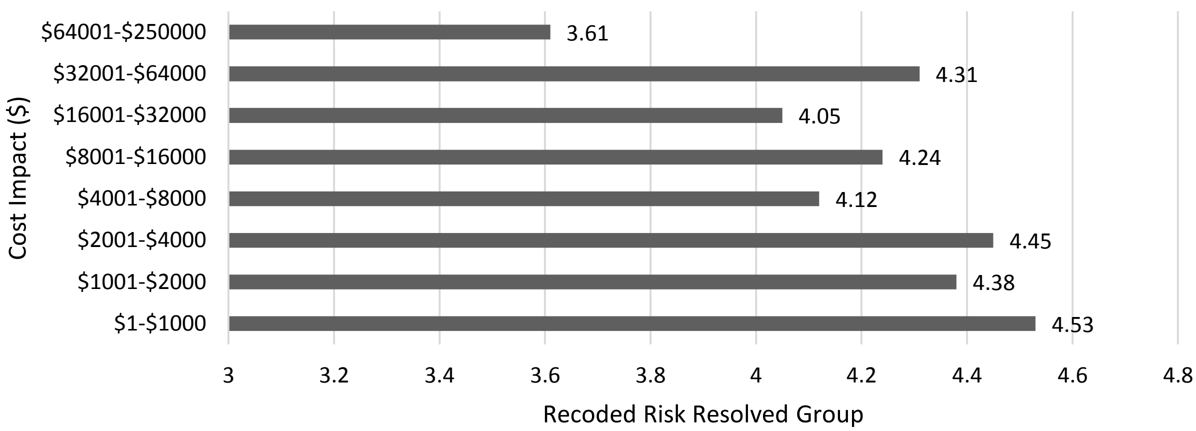

Figure 5.9: Recoded Risk Resolution and Cost Impact Groups

Figure 5.10 shows the regression plot of cost impact and the recoded risk active duration groups. The regression analysis established that the risk active duration statistically significantly predicted the cost impact of the risk. As shown in Figure 5.10, the positive trend line between the cost impact and risk active duration indicated that the longer the risk was being actively managed during a project, the corresponding cost impact tended to be larger.

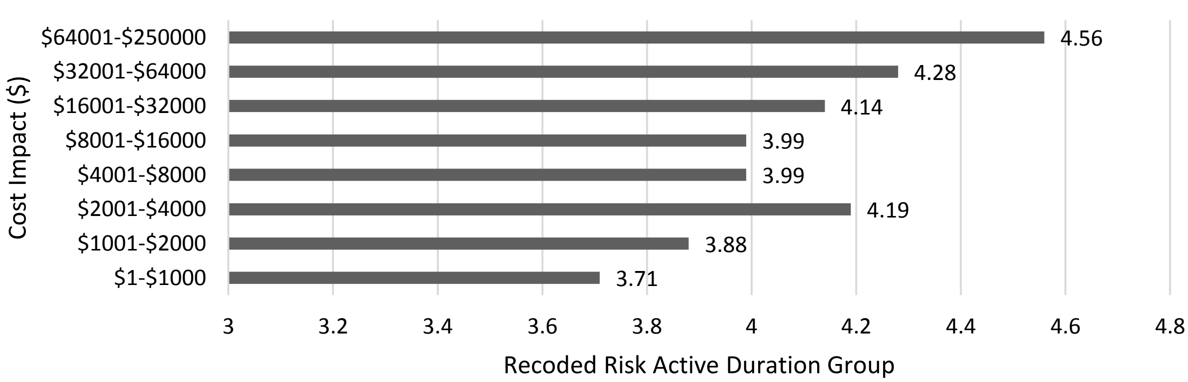

Figure 5.10: Recoded Risk Active Duration and Cost Impact Groups

5.7 Schedule Impact Analysis

To understand the relation between schedule impact of risks and risk characters (Risk identification, Risk Resolution and Risk Active Duration), additional regression analysis using the normalized data was performed. The regression was performed using the recoded groups of schedule impact, as presented in Table 5.13, and the recoded groups of risk identification, risk resolution, and risk active duration, as presented in Table 5.8, 5.9 and 5.10 respectively. Table 5.13 shows the average recoded risk identified, risk resolved and risk active duration group associated with each schedule impact group. Regression analysis was performed using the normalized data and the risks that had positive non-zero impact on the project schedule.

Table 5.13: Recoded Risk Characteristic Mean by Schedule Impact

Magnitude of Schedule Impact (Days)	Count	Average		
		Risk Identification	Risk Resolution	Active Duration
<0 days	6	4.83	4.16	2.5
0 days	1339	3.93	3.91	3.94
1 day-2 days	35	4	4.23	4.43
3 days - 4 days	13	3.31	3.15	4
5 days - 8 days	40	4.43	4.43	4.33
9 days - 16 days	23	4.61	4.74	4.87
17 days - 32 days	26	5.38	5.81	4.23
33 days - 64 days	12	5.5	6	4.92
65 days - 500 days	8	4.38	5.5	5.13
TOTAL	**1502**			

Figure 5.11 shows the regression plot of schedule impact as dependent variable and average recoded risk identification group as the independent variable. The regression analysis established that risk identification did not statistically significantly predict the schedule impact of the risk. As shown in the Figure 5.11, the positive trend line between the schedule impact and risk identification indicated that the risks identified later in the project tend to have greater schedule impacts compared to risks identified earlier in the project.

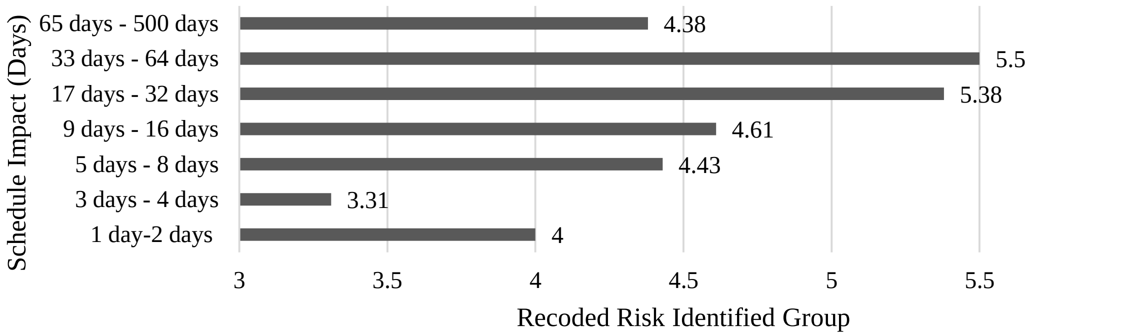

Figure 5.11: Recoded Risk Identification and Schedule Impact Groups

Figure 5.12 shows the regression plot of schedule impact as the dependent variable and average risk resolution group as the independent variable. The regression analysis established that the risk resolution can statistically significantly predict the schedule impact of the risk. The significance and the proportion of variance was equal to 0.0204 (<0.05) and 0.69 respectively. The regression plot shows a positive relation between the schedule impact and risk resolution.

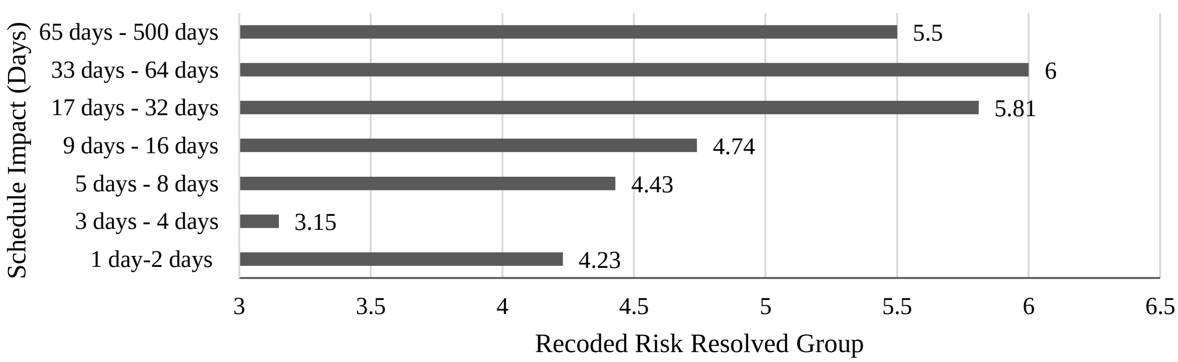

Figure 5.12. Recoded Risk Resolution and Schedule Impact Groups

Figure 5.13 shows the regression plot of schedule impact and recoded risk active duration group. The regression analysis established that the risk active duration did statistically significantly predict the schedule impact of the risk. As shown in Figure 5.13, the positive trend line between the schedule impact and risk active duration indicated that the longer the risk was actively managed by the project team, the greater the corresponding schedule impacted tended to be.

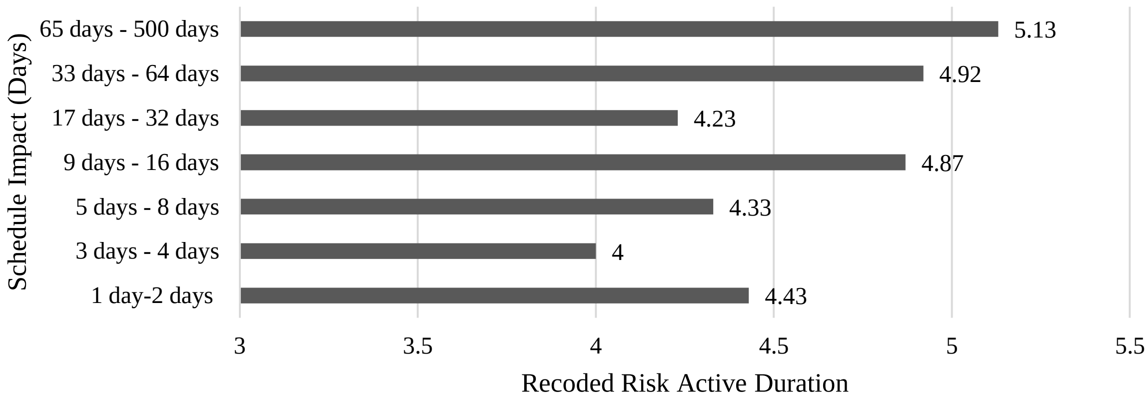

Figure 5.13. Recoded Risk Active Duration and Schedule Impact Groups

5.8 Regression at Project Level

The data collected regarding the project cost overrun and schedule overrun was analyzed using the linear regression to understand the relationship between the dependent variable and independent variable. The linear regression included cost and schedule overrun as the dependent variable whereas the peak risk timing and peak risk magnitude as the independent variable. The regression was performed and the results are shown in Table 5.14.

Table 5.14: Regression Results at Project Level

Sr. No.	Independent Variable	Dependent Variable	R Square	F	P
1	Peak Risk Timing	Cost Overrun (%)	0.017	1.146	0.288
2	Peak Risk Timing	Schedule Overrun (%)	0.038	2.606	0.111
3	Peak Risk Magnitude	Cost Overrun (%)	0.003	0.187	0.667
4	Peak Risk Magnitude	Schedule Overrun (%)	0.004	0.240	0.626

As shown in Table 5.14, the linear regression are not statistically significant as the p value is greater than 0.05. This means that the linear regression doesn't show any significant relationship of peak risk timing and peak risk magnitude with cost and schedule overrun. However, the further investigation of cost and schedule overrun in projects showed positive trend in peak risk timing and peak risk magnitude. The results are explained as under:

5.8.1 Cost Overrun at Project Level

The cost overrun and schedule overrun among the 68 projects varied from 0% to more than 64% of the original contracted cost and schedule. Table 5.15 shows the frequency of projects and the average number of risks, average peak risk timing, and average number of risks at the peak based on sequential doubling the cost overrun groups. The highest number of projects (15), as shown in the table, recorded cost overrun from 4% to 8% of the original contracted cost of the project. It is evident from the table that the average number of risks at the peak loading are comparatively higher for the projects with higher cost overrun. Figure 5.14 shows the plot of cost overrun groups and the mean time of peak loading. The positive trend in the bar graph shows that the projects with peak load timing towards the end of project resulted in greater adverse effect on the overall cost of the project compared to the projects with peaks earlier in the project schedule. Figure 5.15 shows the plot of cost overrun groups and the mean peak risk magnitude. The positive trend in the bar graph shows that the projects with high peak risk magnitude resulted in greater adverse effect on the overall cost of the projects compared to the projects with lower peak risk magnitude.

Table 5.15: Cost Overruns at the Project Level

Cost Overrun	Number of Projects	Mean Risk Number	Mean Peak Timing	Mean Peak Magnitude
<0%	4	15	0.29	6
0%	5	10	0.52	5
0%-1%	9	21	0.59	6
1%-2%	8	12	0.64	6
2%-4%	10	24	0.64	6
4%-8%	15	41	0.74	15
8%-16%	8	16	0.72	7
>16%	9	14	0.74	7
Total	68			

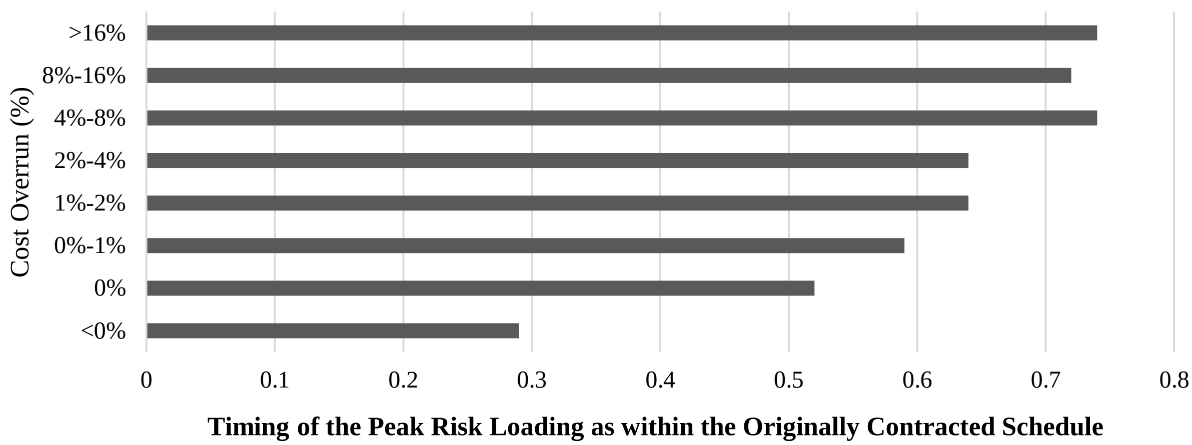

Figure 5.14: Cost Overrun vs Mean Peak Risk Timing

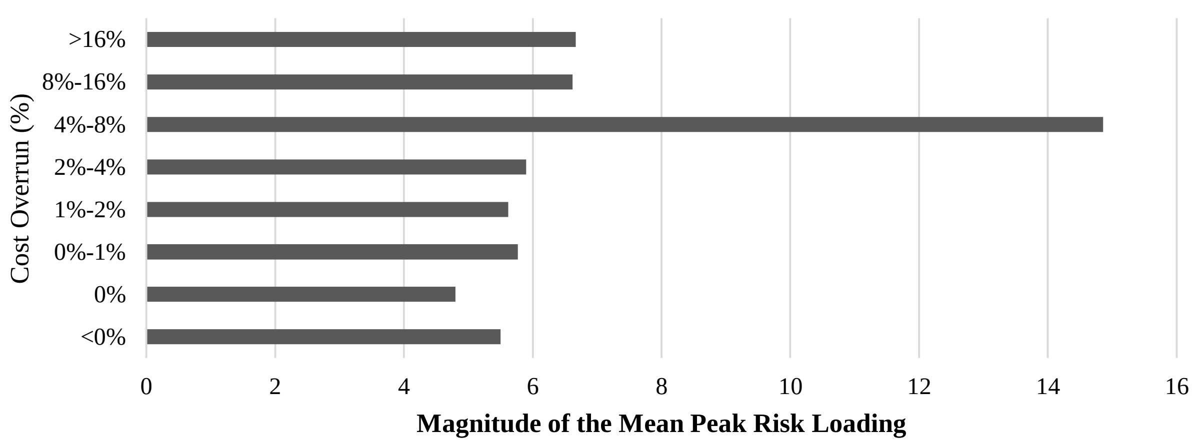

Figure 5.15: Cost Overrun vs Mean Peak Risk Magnitude

5.8.2 Schedule Overrun at Project Level

Table 5.16 shows the frequency of projects and the average number of risks, average peak risk timing, and average number of risks at the peak based on the Schedule overrun groups. Out of 68 projects considered for the research, 23 projects showed 0% change in the schedule of the project whereas only 3 projects showed reduction in the project schedule. The remaining projects showed increases in the original schedule from 1% to more than 64%. Comparatively, the number of projects showing schedule change gradually increased with the increase in schedule delay rate. It is evident from the table that projects with higher schedule impact had higher number of risks and risks at peak, on average, compared to the projects with lower delay rates. Figure 5.16 shows that the peak timing of risks towards the completion of project results in more schedule change. This implies that the later the project team had to deal manage with the peak risk load, the greater the corresponding schedule impact on the project. Similarly, Figure 5.17 shows that the higher peak risk magnitude results in more schedule change. Thus it can be inferred that there exists a positive relationship between the peak risk timing and peak risk magnitude with the cost and schedule overrun of the project.

Table 5.16: Schedule Overrun at Project Level

Schedule Overrun	Number of Projects	Mean Risk Number	Mean Peak Timing	Mean Peak Magnitude
<0%	3	25	0.51	7
0%	23	21	0.56	6
0%-2%	2	18	0.52	6
2%-4%	5	20	0.47	7
4%-8%	5	17	0.58	8
8%-16%	7	28	0.69	11
16%-32%	8	20	0.67	8
32%-64%	7	17	0.95	6
>64%	8	33	0.83	12
Total	68			

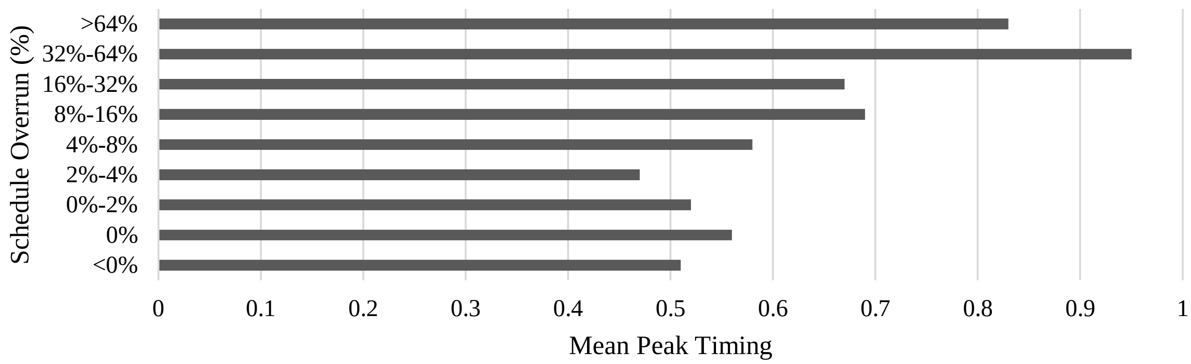

Figure 5.16: Schedule Overrun vs Mean Peak Risk Timing

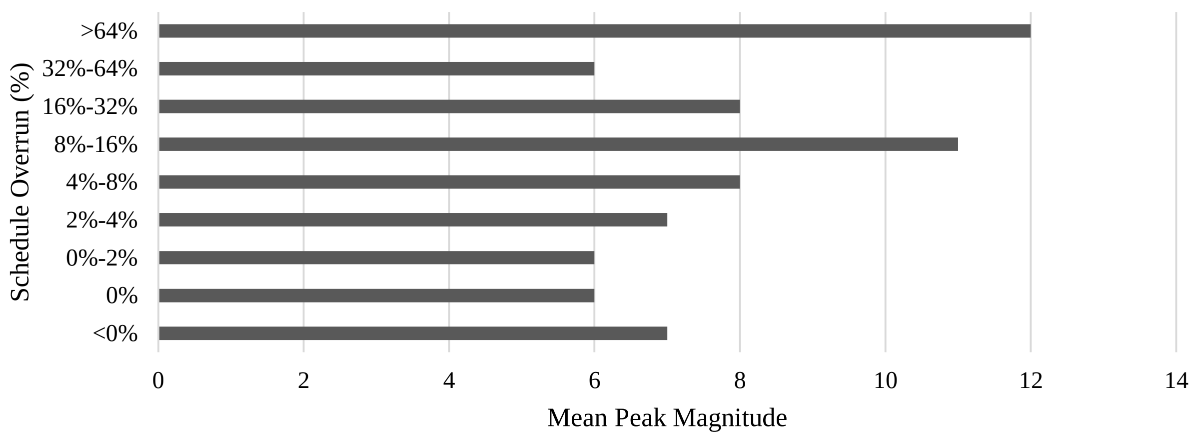

Figure 5.17: Schedule Overrun vs Mean Peak Risk Magnitude

CHAPTER VI – DISCUSSION

6.1 Introduction

This chapter discusses findings and implications of the study results. The research questions raised in this study were are also answered in the chapter. The discussion considers the findings from various stakeholder perspectives within a project team and discusses the results in terms of the risk management actions taken by the construction project team. This chapter discusses an overall risk level distribution in a project, risks identified based on the character and source, relation between the risk characteristics and impacts associated with the risks, statistical data analysis results and findings at the project level describing relation between peak risk loading and overruns in a project.

6.2 Summary of Findings Related to Each Research Question

At the individual risk level, the analysis showed that the risks sources have different characteristics in terms of frequency, timing and magnitude (cost and schedule). Design error/omissions, client scope change and unforeseen concealed conditions were the most frequent risk sources identified from this study, accounting for more than 70 percent of all risks. On average, the risks from design errors, client scope change and unforeseen concealed conditions were identified at 64, 72 and 58 percent of the originally contracted schedule, respectively. These risk sources each had an active duration of 14, 12 and 18 percent of the original schedule duration, respectively. The risks caused by the client scope changes had the greatest impact on the project cost and schedule followed by design errors and unforeseen concealed conditions.

At the individual risk level, the results showed a generalized trend between the risk management actions and the impacts associated with the risks. The cost impacts of the risks showed a negative trend with the risk identification and risk resolution timing, and showed a positive trend with the risk active duration. The schedule impacts of the risks showed a positive general trend with the risk management actions.

At the project level, the findings showed a positive general trend between the peak risk loading (timing and magnitude) and the overall project cost and schedule. The timing of the peak risk loading appeared to have a more defined trend. The more quickly the project team was able to identify the peak number of risk items, the general trend indicated that overall project cost and schedule overruns tended to be lower.

6.3 Characteristics of Risk Distribution within Construction Projects

This study analyzed a dataset consisting of 68 construction projects containing a total of 1502 individual risk events. The identified risks had various impacts in terms of project cost, schedule, or any combination thereof. For identified risks that did have an impact to project cost or schedule, these risks were translated in to change orders that impacted the project's original contracted duration and budget. In many instances, however, did not ultimately result in a directly quantifiable cost or schedule impact to the project. The impact of these risks, however, was not negligible. Even moderate to low level risks require particular attention by the project team to communicate, respond, and resolve the risk in order to mitigate the risk without experiencing a direct impact to project schedule or budget. Of the overall 1502 individual risks that were encountered across the 68 construction projects, 978 risks (65%) resulted in a quantifiable cost impact on the project budget, ranging from as low as a budget reduction of $223,068 to as high as a scope increase of $181,518. From a schedule perspective, only 163 risks (11%) were found to result in a change in project duration, ranging from as low as a schedule acceleration of 29 days to as high as a scope addition of 238 days.

Frequency distributions of risk identification and risk resolution uncovered the timing at which risk management actions are most needed during the construction phase. In terms of overall frequency distributions, both the risk identification and risk resolution profiles had a positive skew, meaning that risk events are front-loaded within the construction schedule. The peak interval of risk identification was between 10 and 20 percent of the construction schedule, with near-peak identification of new risks continuing thereafter through much of the originally scheduled project completion date. Risk identification did not begin to decrease until 90 to 100 percent of the originally contracted schedule duration. Risk resolution was also front-loaded, with a local peak found to occur during the schedule interval of 20 to 30 percent, which indicated early resolution of some risk items. Then risk resolution reached peak frequency during the period from approximately 60 to 90 percent of the project schedule. Taken together, these results show that construction teams must be prepared to continually manage new and potentially unexpected risk events throughout the virtually the entire project schedule.

The distribution of risk identification and resolution across the project schedule somewhat echoed previous studies regarding construction manpower loading curves. Previous research in manpower loading of construction projects shows that the traditional labor levels on a project follow a steady, gradual build-up during early schedule phases, reaching a peak resource load around 45 percent of the project schedule which plateaus through 80 or 90 percent of the schedule, before then seeing a rapid decline of resources to close out the final 10-20 percent of the project (Hanna et al. 1999, Hanna et al. 2002, Moselhi et al. 2005). From a risk management perspective, the distribution of risks visually represented an “inverted” or “reversed” manpower loading curve in the sense that the first 10-20 percent of the construction phase experienced a sudden and rapid increase in risk events, followed by a long peak plateau during the bulk of the project schedule, and ultimately closing the project with an extended and gradual decline in risk events. This reflects that risk events are front-loaded and sudden throughout much of the project schedule, with a gradual reduction at the end of the project schedule. Conversely, labor resources are more gradually increased during early project stages before reaching their extended plateau, and then suddenly and rapidly decreasing near the project's completion date. This may indicate that construction project managers and site superintendents may have the opportunity to identify (and even resolve) a number of risks early in the project prior to reaching peak labor loading, and could potentially optimize their peak labor resources to optimally respond to early risk events.

An interesting finding from this study was that construction projects frequently encounter risk events even after the project's originally contracted completion date has passed. In this study, 82% of the total risks (1230 risks) were identified before the original contracted schedule of the project, whereas the remaining 18% of risks were encountered after the completion of original contracted schedule. This indicated that full, final completion of construction projects often slip beyond their contracted dates, even when substantial completion dates are maintained. As indicated in the Project Data Summary, the 68 projects included within this study were largely high-performing projects, with cost overruns that were substantially below expected industry averages. Yet even in highly successful projects, the construction phase is fraught with risk events that are both challenging and complex for the project team to address. Similarly, even when risks were identified within the original contracted schedule duration, often these risks were resolved after the completion of the original contracted schedule (sometimes causing delays in project completion). Overall, 72% of the risks (1192 risks) were resolved before the originally contracted deadline, whereas the remaining 28% of risks were resolved after crossing the original deadline of the project schedule.

6.4 Characteristics of Risk Sources within Construction Projects

In this study, the identified risks were categorized in to ten different pre-defined risk categories, which reflected the leading root-cause that triggered each risk to occur. These sources of risks were practically related to the individual risks encountered in the construction phase and the categorization of each identified risk was agreed upon by the project team members. Out of all the ten categories of risks, client scope change, designer error/omission, and unforeseen concealed conditions were the most frequently encountered risk sources across the 68 projects in the study sample. These three major risk sources of client scope change (31%), designer error and omissions (33%), and unforeseen concealed conditions (14.45%) contributed to nearly 80 percent of the total identified risks within the construction phase. The remaining 20% of the risk sources were divided amongst client non-scope changes (6%), contractor sub/supplier issues (5%), contractor error/omission (3%), unforeseen unexpected events/weather conditions (3%), client innovation/efficiency (1%), contractor innovation/efficiency (1%), and designer innovation/efficiency (1%).

Within the data sample collected in this study, the risks generating due to client scope change, one of the major source of risk included following risk narratives:

- Owner-directed change in the contracted design of the project which included addition as well as deduction of walls, windows, doors, other kind of room openings, room finishes, etc.
- Change in structural design of the building, which included addition, as well as deduction of roof structural steel, wall reinforcement, etc.
- Change in the mechanical and electrical fixtures of the building.

- Often any modification or value added items in addition to the original contracted scope of work, such installing better security cameras, adding wall flashing above hallway that leaks, updating the old out dated mechanical units, etc. were categorized as client scope changes.

Designer error/omission risks commonly included following risk narratives:

- Change in the design of particular part of the building due to errors in design such as incorrect dimensions, difficult or near-impossible site installations, clashes between structural members, etc.
- Change in design of the mechanical and electrical systems of the structures.
- Change in design as asked by the contractor team to make it more adaptable, considering the constructability of the structure, for instance change in roof drain design, change in plumbing fixture design, change in fire system design, etc.
- Misspecification of materials and finishes, such as improper fire-ratings and incorrect door materials or dimensions.

The third major risk category, unforeseen concealed conditions, included following risk narratives:

- Change due to hidden existing conditions such as asbestos, lead, out dated mechanical systems, error in electrical system, out dated thermal system encountered after demolishing walls and roof, presence of existing boulders encountered during excavation and other items that requires either revision in design or decision from the client.
- Change due to different measurements on site which encountered during the construction phase.

- Change in projects mainly due to different conditions that are encountered after digging the earth or removal of existing structure wall/roof in renovation projects.

The breakdown of risk sources provides further evidence of the complex challenges that face project teams during the construction phase. The projects within this data sample followed the traditional design-bid-build project delivery approach, which means that the 100 percent complete construction documents were completed prior to the construction phase even beginning. Yet the most common type of risk event encountered by participating construction teams was directly linked to design errors and omissions. Further, the second most common risk type was caused by Client scope changes during the construction phase. Taken in combination, these two leading risk source categories indicate that the construction scope continually shifts during the construction phase, even within design-bid-build delivery. This finding is somewhat contrary to conventional wisdom that construction is a well-defined process, particularly in comparison to project design phases, and that the presence of 100 percent complete construction documents means that the project outcomes are largely fixed, certain, or pre-determined. At times, owners act even upon this conventional wisdom by treating construction services as a commodity. The results of this study provide motivation for early contractor involvement in the design phase to perform constructability reviews and other pre-construction services, which have been shown to improve the planning and coordination between design and construction phases (Taylor 2012).

6.5 Risk Management Timing based upon the Root-Cause Source

Each of the ten risk categories were also analyzed in relation to the trends in the corresponding risk management actions of the construction team (risk identification, risk resolution and risk active duration). On average, the risks generating from to designer team (designer error/omissions, designer innovation/efficiency) were encountered earliest at 55% completion of the original contracted schedule. This was followed by risks generated by the client (client scope change, client non-scope change, client innovation/efficiency) at 61% completion of the original contracted schedule. The risks caused by the contractor (contractor error/omission, contractor sub/supplier issues, contractor innovation/efficiency) and unforeseen conditions (unforeseen concealed conditions and unforeseen events/weather) were encountered, on average, later in the project schedule at 64% and 69%, respectively.

In addition to the risk identification timing, this study involved variable that were not accounted for in previous studies. The new variables used in this study were risk resolution timing and the risk active duration. Different risk source groups were found to have different risk resolution timing and risk active durations. For instance, the risks from client, contractor, designer and unforeseen conditions were resolved, on average, at 72%, 79%, 65%, and 89% respectively. Similarly the risks encountered from client, contractor, designer and unforeseen condition had different average active durations, for instance, 11%, 15%, 10% and 20%, respectively, of the original contracted project schedule. The risks resulting from unforeseen conditions were active for longer periods of time, and were resolved later in the project compared to the risks generating from other categories, followed by the risks generated from the contractor team.

Among the individual risk sources, the earliest identified risk categories were related to project innovations and efficiencies. However, these events were among the least frequently encountered events, regardless of whether the source came from the owner, contractor, or design consultant. Client non-scope changes were also among the earliest identified risk types. Client non-scope changes typically indicated a lack of timely client decision-making, delays with internal approvals, challenges in the deployment of client resources, and even conflict between internal client stakeholder groups. Since these risk items did not include explicit client-directed changes in project scope, this finding was somewhat surprising as the researchers expected that Client teams may be reluctant to admit to a lack of internal coordination.

Owner-directed scope changes were among the latest-occurring risk sources, on average being identified at 72 percent and resolved at 84 percent of the contracted schedule. Upon first glance, particularly considering the successful performance of the particular projects within the data sample, it may be expected that late-occurring Client scope changes would be a result of expenditures of unneeded project contingencies. However, as noted in the previous section, a review of the actual narrative descriptions of discrete risk events revealed that the majority of Client-direct scope changes were from late decisions and changes from the Client user groups. This result is supported by previous studies which have found that slow client decision-making often has a substantial impact on construction operations (Doloi et al. 2012, Gunduz et al. 2013, Odeh and Battaneh 2002). Furthermore, the client groups within this study were large public agencies with typically have lengthy and multi-step approval processes before scope changes can be formally integrated into the project budget.

Other late-occurring risk sources were contractor sub and supplier issues as well as unforeseen unexpected events and weather. The late timing of contractor sub and supplier risks reflects the difficulty of coordinating long lead time items as well as last-in-line sub trades, often referred to as the "parade-of-trades" (Han and Park 2011, Mitropoulos et al, 2014, Tommelein et al. 1999). The late identification of truly unforeseen and unexpected events, outside of more traditional concealed conditions, was perhaps reflective of a certain psychology wherein project teams may mutually ascribe late-occurring issues as being "unforeseen" and "unexpected" to avoid late-project "blame games" of which stakeholder was truly at fault.

6.6 Relationship between Risk Management Actions and Cost Impacts

In addition to the relation of the risk characteristics with the risk categories, the timing of risk management actions taken by the project team were documented and analyzed in relation to the cost impacts of the encountered risks. The relationship between the risk management actions (consisting of risk identification, active duration of risk mitigation response, and risk resolution) and the risk impacts in terms of cost on the project were tested using the statistical methods of linear regression analysis and ANOVA. The cost impacts of the encountered risk were, somewhat surprisingly, negatively related with risk identification and risk resolution timing, which means that risks with greater cost impacts were typically identified earlier in the project schedule. On the other hand, the risk active duration showed a positive trend with the cost impact, which indicated that the longer the risk was open (and therefore consuming the project team's time, energy, resources, and attention to mitigate the risk), the cost impact of the risk tended to be larger.

When considering the relationship between risk management actions and corresponding cost impacts, it is noted that the timing of risk identification was found to have the strongest relationship with the corresponding cost impact. This was concluded based upon the largest coefficient of determination (R^2=0.83) and the strong statistical significance (p=.001) of the normalized linear regression between risk identification and cost impact, as compared to the normalized regressions for risk active duration (R^2=.76, p=.005) and risk resolution (R^2= 0.62, p=.02). This finding may be indicative of the fact that it is important for project teams to proactively communicate potential cost impacts early on during the construction phase. Further, the finding that larger cost impact items required a longer risk active duration may show that larger risk items can be identified early, but then require a significant amount of time for the project team to fully mitigate the risk. This perhaps shows the complexity of the response processes with which large risk events are analyzed, negotiated, and integrated into project operations.

6.7 Relationship between Risk Management Actions and Schedule Impacts

The schedule impact of the encountered risks showed a positive trend with the timing of the project team's risk management actions. This means that when risks were identified and resolved later in the project schedule, their corresponding schedule impact tended to be larger. Also, the longer that a risk was open for the project team's mitigation actions, the greater the schedule impact related to the risk.

When analyzing the normalized linear regression results, it was noted that the only statistically significant relationship was between the timing of risk resolution and schedule impact (R^2=0.69, p=0.02). The fact that risk identification did not have a statistically significant relationship with schedule impact was perhaps indicative of the fact that, when a risk is initially encountered, project teams may be more optimize that they will recover the lost schedule time later during the project. Another consideration is that when potential cost impacts are identified, the owner often has a pre-defined contingency budget to cover the additional costs. Yet from a schedule perspective, the owner rarely allots a pre-defined schedule cushion to accommodate schedule overruns. Due to these contractual realities, there may be a human social dynamic where project teams are incentivized to be optimistic about schedule impacts when identifying risks earlier in the project. The fact that all three risk management actions – identification, resolution, and active duration – were statistically significantly related to cost impact, yet only resolution was significant when considering schedule impacts, may also suggest that cost impacts are more tangible and easily definable than time impacts. A supporting trend was that the longer a risk item was active/open, the more likely it was to have a larger schedule impact. This may show that risks that impact schedule tend to drag on longer before they are resolved, and ultimately become resolved late in the project schedule when there is no longer any room for optimism that lost schedule time can realistically be recovered.

6.8 Implications of Risk Management to Project-Level Cost and Schedule Performance

The analysis at the project level considered the peak occurrence timing, peak risk magnitude, the cost overrun, and the schedule overrun as the four main variables in understanding the relation and importance of risk management throughout the project life cycle. On average, for 68 projects under this study, the peak occurrence of the risks was at 62% of the original contracted project schedule. Out of the 68 projects under study, only 5 (7%) projects were delivered on contracted budget. Similarly, 23 projects (34%), out of 68 projects experienced zero schedule delays. The average change order rate in budget of project and schedule of project was recorded as 7.17% and 25.56%, respectively. Each project was individually analyzed to find the timing of peak occurrence of the risks along with number of risks at the peak.

Linear regression was used to analyze the project level data. The linear regression results showed non-significance in predicting the relationship between the peak risk timing and peak risk magnitude with the cost and schedule overrun. The further investigation was conducted and the analysis resulted in to the finding that the risk peak occurrence timing in projects had a positive trend with the cost overrun and the schedule overrun of the project. This means that the projects that experiences higher number of active risks towards the end of the project completion schedule has a higher potential for increase in the contracted project budget. The results also showed that the peak risk magnitude had a positive trend with the cost and schedule overrun. The positive trend means that the projects having higher number of risks at the peak tends to have higher schedule overrun in the projects. Similarly, the projects that has higher number of risks active towards the completion of the projects shows high potential for schedule overrun in the projects.

A contribution of this study was the creation of a new indicator, risk loading, to quantify the total number of risks that are being actively managed by the project team at any given time within the construction schedule. The overall risk loading profile figure provided within the Data Analysis section offers new perspective of the complexity of the building construction process. The plot shows a steady increase in the total number of active risk events during the first 40 percent of the project schedule. Then, the construction phase is nearly at its peak loading of active risks from 40 through about 80 percent of the contracted schedule (with the absolute peak occurring at 60-65 percent). The total number of risk items that require the project team's attention are much greater than the number of items that ultimately result in quantifiable cost or schedule impacts, which are in turn often "bundled" together into change orders. The results of this study demonstrate that research designs that simply analyze change orders, even when the unit of measure is on the level of individual change orders, are significantly under-estimating the true impacts that risks have on project time, resources, and attention of the participating stakeholders.

6.9 Chapter Summary

This chapter summarized the analytical results at both the risk and the project level. The results were discussed based on the findings of risk distributions within a building construction project, risk categories, cost and schedule impacts of the risks, and at the project level. This chapter discussed the results of descriptive analysis as well as inferential analysis conducted on the data.

The next chapter concludes the results of this study along with limitations and future research recommendations.

CHAPTER VII – CONCLUSION

7.1 Introduction

This chapter concludes the thesis with a summary of the research objectives, methodology, and associated findings. Implications of the findings to risk management practices and construction project control are discussed along with the specific contributions of the research. This chapter concludes by examining the inherent limitations of the study and recommends further areas of research within the topic of construction risk management and project control.

7.2 Conclusion

Risk management is a critical aspect of effective construction project control. In order to investigate the influence of risk management actions on project performance, this study systematically documented all risk events (N=1502) encountered by project teams across the construction phase of 68 construction-building projects. The research approach defined various variables to statistically understand and build a bridge between the risk management actions of the project team and the impacts of risks on the construction project, along with other risk characteristics such as the root-cause source of each individual risk. The researchers introduced two new variables – risk resolution timing and risk active duration timing – that have not been empirically measured in previous studies. Moreover, definition of risk loading and the corresponding peak occurrence of all active risks items in a particular project was related with the project's overall cost and schedule performance, which was the first time this concept has been defined and empirically measured researchers in the field of risk management within construction engineering and management. Results of the study indicate that unique risk sources have different characteristics related to cost and schedule impacts as well as the timing of associated risk management actions. Statistically significant relationships were discovered for the timeliness of the project teams' risk identification, response, and resolution actions with the corresponding cost and schedule impact of each risk. In this manner, the study contributed a better understanding construction risk management at individual risk level as well as at the project level.

Whereas much risk management research in the construction industry has analyzed change orders, this study contributes an additional level of detail by studying individual risk events. This additional level of detail is important because a single change order often reflects the combined cost and schedule impacts from multiple risk events; further, many risk events occur during the construction process that do not result in change orders yet still require substantial risk management effort to be expended by the project team. Previous studies included risk management, causes of change orders, and impacts of change orders. This research shows that the change orders are resulted from the identified risks on the project. These risks are categorized based on the source and the impacts in terms of cost and schedule are analyzed to determine the relation between them. The change orders resulting from individual risks ultimately impacts the project by directly changing the contracted cost and schedule and indirectly affecting the efficiency and productivity of labor resources.

To understand the potential relationship between project team risk management actions and the magnitude of risk impacts to cost and schedule, statistical methods such as linear regression analysis and ANOVA test were used along with descriptive analysis of the project data. The results shows that the risk management actions are related to the impacts of the risks on the project cost and schedule. The cost impact of the risks are negatively related to the risk identification timing and risk resolution timing. Whereas, there is a positive relation between the cost impact and the active duration of the risk. Previous studies have also shown a statistically significant trend in the cost impact based on the when the risk was introduced to the project (Perrenoud 2015). The finding from this study contradicts with the hypothesis statement related to the cost impact and the risk characteristics.

The schedule impact and the risk identification timing are positively related to each other which is consistent to previous studies (Ibbs 2005). The risks that are identified later on the project schedule has more adverse effects on the schedule of the project. The previous studies considered the timing of risks when they occurred on the project, but they did not take the time period for which the risks were active on the project schedule and the risk resolution timing. This study also included the active duration of risk for which the project team has to deal with the risk until the risk was resolved in addition to the risk identification and risk resolution timings. The regression results showed a positive trend in the schedule impact associated with the active duration of the risk and risk resolution. This means that the risks which are identified and resolved towards the end of project and the risk that are open for longer period of time has considerably greater impact on the schedule of the project. The finding satisfies the hypothesis statement related to the schedule impact and the risk characteristics.

At the project level, descriptive and statistical regression method was used to understand and answer the research questions. The results shows that there exists a positive relation between the peak occurrence timing and the cost overrun and the schedule overrun of the project. This means, there are higher potential of cost and schedule overrun of a project if large number of risks are active half way through the project schedule. The finding is based on the collectively data analysis across the 68 projects and change in cost and schedule related to these projects. The finding from this study satisfies the hypothesis statement related to the project level risk management.

7.3 Research Contributions

Considering the fact that cost and schedule overruns are all too common within the construction industry, the objective of this study was to better understand the risk distribution across the construction phase and the relationship between risk management actions and corresponding impacts to project cost and schedule. This research contributes the existing body of knowledge relating to risk management in construction by showing the distribution of risk occurrence across the construction phase and documenting the most prevalent root-cause sources of risks within design-bid-build projects in the vertical sector.

Results from this study are useful for project management teams to understand in terms of the sheer complexity and amount of resources required to successfully manage the numerous potential risk impacts that face a construction project. Moreover, the regression models obtained from the data analysis may be used by the project management team to augment predictions of the potential impact of risks on a project. The finding at the project level data analysis can be used by the project management team to understand the nature of risk load and effects related to peak load timing. Efforts can be made by the project management team to understand this study and relate it with the real life projects to pro-actively manage the encountered risk keeping in mind the adverse effects associated with the risk characters and peak risk loading in a construction project.

This study contributed multiple new variables to empirically measure the risk management actions of construction project teams. The timing of risk resolution and risk active duration were new variables that have not been addressed in previous studies. Further, this study proposed a new term, risk loading, to account for the volume of risks that were open (and therefore being actively managed) at all points throughout the project schedule. The new risk loading variable enabled a more granular and detailed measurement of the distribution of risks across the construction phase.

This variable also facilitated project-level measures of risk management actions, by quantifying the magnitude and timing of the peak risk loading experienced on a project-by-project basis.

The statistically significant relationships between cost and schedule performance and risk management actions at both the project-level (timing and magnitude of peak risk loading) and individual risk level (identification, resolution, active duration) are expected to encourage greater transparency and collaboration among construction project teams. The analysis of root-cause risk sources revealed that all project stakeholders, including the owner, design consultant, contractor, subcontractors, and suppliers are responsible for causing – and mitigating – project risk factors. Results contribute empirically validated evidence that project performance can be improved by clear, early, and open communication of risk management needs throughout the construction phase. There is potential benefit to bottom-line project performance if project teams are willing to more openly share project risks, including all "near miss" items, and to communicate them in a proactive manner *before* they have resulted in a cost or schedule impact. As described by Ibbs (2003), the cumulative impact of change orders may be much greater than their discrete cost and schedule values. This is further emphasized by Ibbs' (2005) study, which found changes that occur late in the project schedule are nearly twice as detrimental to productivity. Early identification and proactive mitigation of risks is therefore critical to potentially result in less productivity impacts due to having a well-informed and well-prepared project team. A unique aspect of the research design was that many of the risk events within the compiled dataset did not result in a quantifiable cost or schedule impact to the project. By measuring the characteristics of all risks that occurred, and not simply restricting data collection to change orders, this study contributes a much more refined, discrete, and detailed unit of measurement within the field of construction risk management. Measurement of all risk events includes "near miss" risks that occurred and were dealt with by the project team but did not ultimately result in cost or schedule impacts to the project. In more traditional research designs, these type of risk events would simply be omitted due to their lack of cost or schedule impact. Yet this is deceptive in terms of the impacts that risk can have a on a construction project, particularly in light of the fact that even when risks that do not result in cost or schedule impacts, they still consume project resources in the sense that they require risk management actions, focus, and effort to be expended by the project team.

Utilizing the change order as the unit of measure, as done in many previous studies, can be extremely misleading from a timing perspective. This timing viewpoint typically reflects the point at which the change order documentation is formally executed between the owner and contractor organizations, which means that all scope line items and associated pricing and supporting documentation have already been defined by the contractor, reviewed by the owner's consultant and owner's representative, all back-and-forth discussions, questions, and negotiations have occurred, and the final change order information has been sent up through the owner organization's hierarchy in accordance with their internal approval process. It is not unusual for this process to require weeks or months of time, and the lag time between the contractor's change order submission and achievement of final owner approval can vary widely from change order to changer order. This means that the approval timeline for each change order typically contains a significant – and widely inconsistent – delay from when the change event was actually experienced on-site. Change orders are therefore not an accurate reflection of the timing of the project team's corresponding risk mitigation actions.

Moreover, owner project managers are at times incentivized to hold off on submitting small change orders to their superiors, choosing rather to "bundle" together multiple small change items into a single change order. This phenomenon is often motivated by an effort to minimize associated paperwork and also to reduce the perceived number of change orders that the project has encountered. The procedures of bundling and/or intentionally delaying change order submissions introduces additional uncertainty into the true timing of individual change events, and provided the impetus for the research design of this study to focus on the occurrence of every discrete risk item that occurred during the construction phase. The chosen unit of measure in this study was developed with a "reduction-to-practice" focus which accounted for the above-described conventional change order practices within the industry in a manner to make findings directly applicable to the construction project environments that face industry practitioners.

Further complicating matters, a single change order is often comprised of multiple individual scope items. The associated cost and schedule impacts of the change order are thus a manifestation of multiple separate risk issues that occurred on the project. For example, a single change order during the construction phase of a renovation project may account for any combination of multiple design errors and omissions (perhaps misspecification of materials, clashes in mechanical system locations, etc.), unforeseen concealed conditions (such as asbestos, lead paint, underground environment), and owner scope changes (any combination of scope additions, deletions, adjustments). Research studies that claim to link each change order to a single root-cause must be treated with some skepticism, as any particular change order is oftentimes comprised of multiple risk items.

7.4 Limitations and Recommendations for Future Research

The main limitation of the study is the sample size of only 68 construction projects, which opens the future research scope by increasing the dataset not only in terms of the quantity of projects, but also in terms of expanding the variety of project types, sizes, and construction sectors. The research is limited to the project data from minor construction projects with an average cost and schedule of $2 million and 203 days respectively. Future research can be focused on infrastructure projects with higher dollar and schedule values.

A limitation of the study was that the cost impacts that were quantified only reflect costs that directly changed the original contract values. In other words, if a risk item did not result in an approved change order, the cost impact was recorded as zero dollars. In this manner, only costs that were paid by the owner were measured. This opens the possibility that internal costs borne by the contractor (and not reimbursed by the owner) were not captured by the data collection tool.

The data collection tool utilized within this study – the Weekly Risk Report – represents a data collection tool that has broad applicability within construction engineering and management research. Future research is recommended to apply this tool to quantify and understand the typical risk profiles of specific project types. Further research is also recommended to measure the risk management performance of entire programs and construction portfolios of various construction organizations. The data collection tool could be used to benchmark risk management practices within the industry and compare performance between organizations, departments, contractors, designers, and project team individuals.

In addition to the above limitations, another limitation is the multicollinearity issue with the independent variables of risk identification and risk resolution. This limited the use of available data to predict the impacts on project cost and schedule based on considering both risk identification timing and risk resolution timing. At a time, only one variable can be used to predict the cost and schedule impact of the risks on a project. The future research direction can include the use of different statistical methods to understand the relation between the dependent and independent variables, which will eliminate the multicollinearity assumption and broaden the horizon of results in risk management in construction project life cycle.

7.5 Summary

The research, despite limitations, shows the relationship of the risk identification, risk resolution and risk active duration with the impact of risks in terms of cost and schedule. The regression model predicts the schedule impact significantly based on the risk identification and also based on the risk active duration, adding to the previous studies. The research concludes that the delays in construction projects can be higher if more risks are introduced towards the end of projects and kept open for longer time by not resolving them.

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APPENDIX A – Weekly Risk Report

Award Tab

	AWARD INFORMATION - CON
	NOTE: Green Cells are Auto-Calculated
	Red Cells must be input to support the Director Report
Owner	
Project Number	
Project Name	
Project Type	
Fiscal Year Awarded	
Procurement Method	
Status	
Close Out Survey is Completed?	
Pre-Award Clarification	
Project Manager	
Client PM Department	
End User/Requestor	
Parent/Funding	
Planner	
External Consultant	
Dalhousie Client	
Awarded Vendor	
Vendor PM	
Vendor Site Superintendent	
Awarded Cost	
Project Start Date	
Scheduled Completion Date (at Contract Award)	
Inherent Project Risk	
	10 = Extreme High Risk & Complexity **5 = Above Average Risk & Complexity** **1 = Average/Typical Risk & Complexity**

Risks & Innovations Tab

#	DATE IDENTIFIED	SOURCE OF THE RISK / INNOVATION	RISK / INNOVATION BRIEF NARRATIVE DESCRIPTION (Note: Press "ALT+ENTER" to Create a New Line within a Cell)	ACTUAL DATE RESOLVED	SCHEDULE IMPACT	COST IMPACT	Satisfaction with Contractor's Risk Response	INSTITUTIONAL RISK SEVERITY
0	1/15/09	Please identify the responsible party & category for the risk (from the drop down menu)	Please describe the details of the risk: 1. What is the risk / brief description of the background? 2. What will be done / what is the action plan to minimize this risk? 3. Who is responsible for specific actions? What actions are most pressing and when are they needed? 4. Brief narrative of the risk impact (potential or actual impacts to cost, schedule, quality)? 5. Any on-going, week-to-week updates to this risk (if applicable)	2/1/09	15	$10,000	1-10 Scale	10 = Major Institutional Impact 5 = Moderate Institutional Impact 1 = Project Level Impact Only
1								
2								
3								
4								
5								

Summary Tab

0
Weekly Risk Report
July 17, 2016

Project Number:	**0**	Percent Complete:	
Project Name:	**0**	Overall Client PM Satisfaction:	-
Project Manager	**0**	# Unresolved Risks:	**0**
Vendor:	**0**	# of SEVERE Risks:	**0**

Cost Analysis		**Schedule Analysis**	
Awarded Cost:	$0	Awarded Completion Date:	0-Jan-1900
Scope Reallocations:	$0	Scope Reallocations:	0
Current Baseline:	**$0**	**Current Baseline:**	**0-Jan-1900**
Total Cost Impacts:	$0	Total Schedule Impacts:	0
Current Project Cost:	***$0***	***Current Project Completion Date:***	***0-Jan-1900***
Percent Cost Impact:	***#DIV/0!***	***Percent Schedule Impact:***	***#DIV/0!***

Project Schedule Analysis	**Number of Risks**	**Cost Impacts**	**Schedule Impacts**
OVERALL CLIENT IMPACTS	**0**	**$ -**	**0**
CLIENT: Scope Change	0	$ -	0
CLIENT: Non-Scope Change	0	$ -	0
CLIENT: Innovation / Efficiency	0	$ -	0
OVERALL CONTRACTOR IMPACTS	**0**	**$ -**	**0**
CONTRACTOR: Error / Omission / General Issues	0	$ -	0
CONTRACTOR: Sub / Supplier	0	$ -	0
CONTRACTOR: Innovation / Efficiency	0	$ -	0
OVERALL DESIGN IMPACTS	**0**	**$ -**	**0**
DESIGNER: Error / Omission	0	$ -	0
DESIGNER: Innovation / Efficiency	0	$ -	0
OVERALL UNFORESEEN IMPACTS	**0**	**$ -**	**0**
UNFORESEEN: Concealed Conditions	0	$ -	0
UNFORESEEN: Unexpected Events / Weather	0	$ -	0
OVERALL TOTAL IMPACTS	**0**	**$ -**	**0**

OTHER: Scope Reallocation to/from Separate Project	**0**	**$ -**	**0**

Client Change Order Rate:	#DIV/0!	Client Schedule Impacts:	#DIV/0!
Contractor Change Order Rate:	#DIV/0!	Contractor Schedule Impacts:	#DIV/0!
Design Change Order Rate:	#DIV/0!	Design Schedule Impacts:	#DIV/0!
Unforeseen Change Order Rate:	#DIV/0!	Unforeseen Schedule Impacts:	#DIV/0!
Non-Contractor CO Rate:	#DIV/0!	Non-Contractor Delay Rate:	#DIV/0!

APPENDIX B – Sample Weekly Risk Report

(Project: PHASE 1 - Exterior Envelope Conservation, Henry Hicks)

	AWARD INFORMATION - CON
	NOTE: Green Cells are Auto-Calculated
	Red Cells must be input to support the Director Report
Owner	Dalhousie University
Project Number	2015-007
Project Name	PHASE 1 - Exterior Envelope Conservation, Henry Hicks
Project Type	Envelope Conservation
Fiscal Year Awarded	**2015**
Procurement Method	Best Value
Delivery Method	**Design-Bid-Build (DBB)**
Estimated Budget	
Source of Estimate	
Status	**In Progress**
Close Out Survey is Completed?	**No**
Pre-Award Clarification	Yes
Project Manager	Garry Martell
Client PM Department	FM - Minor Projects
End User/Requestor	
Parent/Funding	
Procurement Representative	**Mike Drane**
Planner	
External Consultant	Kassner Goodspeed Architects (Richard Kassner)
Dalhousie Client	
Awarded Vendor	Coastal Restoration
Vendor PM	Bradley Lanteigne
Vendor Site Superintendent	Kevin Dewolfe
Proposal Cost	**$1,531,485**
Proposal was the Lowest Cost	**Yes**
Approved Value Added Items (Addition)	**$165,500**
Approved Value Added Items (Savings)	**$27,250**
Approved Value Added Items (Net Value)	**$138,250**
Other Approved Scope Changes	**($39,256)**
Awarded Cost	**$1,630,479.00**
Awarded Cost vs. Budget	**-**
RFP Issue	**2-Feb-2015**
Project Start Date	**8-May-2015**

Scheduled Completion Date (at Contract Award)	**27-Mar-2016**
Awarded Project Duration (Total days)	**324**
Approved Value Added Items (Addition)	
Approved Value Added Items (Savings)	
Approved Value Added Items (Net Value)	
Other Approved Scope Changes	
Awarded Duration (Total days)	**324**

Target RFP Closing	**24-Feb-2015**
Target Interviews	**3-Mar-2015**
Target Selection of Bidder	**10-Apr-2015**
Target Notification of Award	**8-May-2015**
Target Proposal Duration	**22**
Target Evaluation Duration	**45**
Target Pre-Award Duration	**28**
Target Procurement Duration	**95**

Actual RFP Closing	
Actual Interviews	
Actual Selection of Bidder	
Actual Notification of Award	
Actual Proposal Duration	**-42037**
Actual Evaluation Duration	**0**
Actual Pre-Award Duration	**0**
Actual Procurement Duration	**-42037**

Inherent Project Risk	
	10 = Extreme High Risk & Complexity **5 = Above Average Risk & Complexity** **1 = Average/Typical Risk & Complexity**

#	DATE IDENTIFIED	SOURCE OF THE RISK / INNOVATION	RISK / INNOVATION BRIEF NARRATIVE DESCRIPTION (Note: Press "ALT+ENTER" to Create a New Line within a Cell)	ACTUAL DATE RESOLVED	SCHEDULE IMPACT	COST IMPACT	Satisfaction with Contractor's Risk Response	INSTITUTIONAL RISK SEVERITY
0	**1/15/09**	**Please identify the responsible party & category for the risk (from the drop down menu)**	**Please describe the details of the risk: 1. What is the risk / brief description of the background? 2. What will be done / what is the action plan to minimize this risk? 3. Who is responsible for specific actions? What actions are most pressing and when are they needed? 4. Brief narrative of the risk impact (potential or actual impacts to cost, schedule, quality)? 5. Any on-going, week-to-week updates to this risk (if applicable)**	**2/1/09**	**15**	**$10,000**	**1-10 Scale**	**10 = Major Institutional Impact 5 = Moderate Institutional Impact 1 = Project Level Impact Only**
1	5/22/15	UNFORESEEN: Concealed Conditions	**1. Window pricing did not include opaque glass for the bathroom windows / original windows that we looked at had clear glass.** 2. Contacted window supplier for pricing	6/23/15	0	$ -	10	**N/A**

			3. Client / Consultant to determine if opaque glass is necessary 4. Only impact is cost. Delivery of these windows will be in phase 2. 5. The cost will be $2,084.78 plus Hst for all 5 bathroom windows. Garry confirmed that this item will be carried forward in Phase 2 works.					
2	6/2/15	UNFORESEEN: Concealed Conditions	**1. Noise and dust are an issue for the building occupants** 2. Cover windows with a combination of plastic, acoustic panels, insulation and/ or plywood 3. Consultant / client/ Contractor to come up with a viable solution 4. Using the plastic and insulation method will not impact cost or schedule. 5. The dust control coverings seem to be working fine.	6/2/15	0	$ -	10	**MODERATE**

3	6/2/15	CLIENT: Non-Scope Change	**1. Decision on the final window sizing and glass coating type to be approved** 2. Install a mockup window in the 2nd floor hallway 3. Once window has arrived and is installed the stock holders representatives in the building will decide. 4. As long as the window type is approved the schedule will only be impacted by 2 -3 weeks. If its not approved and another mockup window needs to be ordered then the schedule has a risk of being greatly impacted by the delay. Also note that the schedule is also dependent on the supplier getting the mockup windows to the contractor as indicated. 5. The electrical room window is in hand but it has been determined that this window should have an aluminum panel on the top sash for venting hoods. Also this window to have pinhead glass. Schooner will install the mock up electrical window in a temporary	6/30/15	0	$ -	10	**MODERATE**

			framed opening to simulate what's existing in the building. This will be ready at the same time as the 2nd floor mockup window. The electrical room window details have been provided along with the shop drawings. It has been confirmed that the holes in the top panel section be cut out later (by Rivet Sheet Metal) once the window is installed. The new windows have been approved and ordered on June 30, 2015.					
4	6/10/15	CONTRACTOR: Sub / Supplier	**1. The window supplier (Marvin) said that the 2nd floor mock up window delivery date will be here on June 25 instead of June 18.** 2. Schooner (Window Installer) will do a mockup window using the electrical room window inside a temporary framed opening. They will also have the 2nd floor window out and ready so that the new window can be installed as soon as it gets to site. 3. Supplier to ensure	6/30/15	0	$ -	10	**N/A**

			that the mockup window delivery doesn't get delayed any longer. 4. This will push back the approval of the windows by another week. 5. Mock up window was delivered on June 26th and installation completed on June 27th. Stakeholders meeting was held on June 29th for review and feedback was positive.					

5	6/17/15	CLIENT: Non-Scope Change	**1. Yankee Gutters.** 2. Complete water tests and inspections to determine effectiveness of the Yankee Gutters. 3. All parties are responsible to problem solve and to come up with a solution. 4. Until the scope of work is determined this will remain a risk because of the unknown cost and the amount of time required to complete the work. 5. If required the crew size will be increased so that the job schedule does not get affected. This only applies for the Yankee gutters in phase 1A and the area on the south elevation of the south wing. The water test was completed on Monday July 13th. It was determined that further investigation / water testing is required. A second water test was completed and no water leaks were found through the gutters. It was determined that further water testing is needed for a longer duration of time once	10/21/15	0	$(41,538.40)	10	**N/A**

			the wall dries out. Some water was detected after the water test from the gutters. A section of gutter will be removed for further investigation. 3 days of dry weather will be needed to complete. It was determined that the Yankee gutter could not be taken off for inspection without damaging the roof. A liner for the gutter is being looked into as a possible solution. Robert is waiting to hear back from Cornerstone for further product information and pricing from their approved applicator. Robert provided details to Roof Works and we are waiting for a price to install the Kemper System. Bradley has reservations about the warranty and product performance and asked the question if Roof Works could provide the warranty directly for Dalhousie. A meeting has been scheduled with all parties involved. CRM is putting the prices together and will have					

			it ready for review early next week. A price with the breakdown has been issued and waiting on CO. A revised price of $33,461.60 plus HST has been submitted which will result in the decrease of the contract amount by $41,538.40. As per email Roofworks are scheduled to begin the work on October 27, 2015. A CO Has been received, signed and waiting on owner signatures. A water test was completed on the South Elevation of the South Wing. A leak was found and it is believed to have been coming in from a seam that was just beyond where the scaffolding is at. CRM is going to try to modify the scaffolding to reach this seam but if not this could be done from a man lift. The scaffolding has been modified and waiting for Roofworks to complete along with the section of gutter in phase 1B. Roofworks will be there this week to correct deficiencies.						

6	6/24/15	CLIENT: Non-Scope Change	**1. 3rd party window testing for water and air leakage.** 2. Complete testing on the windows as soon as possible so that if there is a failure it can be addressed right away. 3. Contractor to ensure that the 2nd floor mockup window be ready for testing ASAP. Dalhousie and consultant to set up testing. Manufacturer / Contractor to correct any issues (if necessary). 4. If the window testing fails then this could delay the delivery and installation of the window schedule. 5. The window testing will be co-ordinated for the 2nd week of August. Schooner Is scheduled to remove the interior trim on Friday Aug. 14th for Thermal wise to complete the testing on Wednesday Aug. 19th. Thermal wise has rescheduled to start the testing on Wed. Aug. 26th. and be completed by Fri. Aug. 28th. Some water was	8/17/15	0	$ 3,739.89	10	**MODERATE**

			detected through the shims under the window and a different method of providing a seal is being looked into. Robert provided SI#005 with details of the additional steps to take and schooner is going to price the difference in product cost. A price ($3,739.89) has been provided and waiting for official Change Order. The material has been ordered and will be installed to the remaining windows as soon as it arrives. A second test will be completed after the new window water stop details are completed. CO # 3 has been issued and product is scheduled to arrive the week of Sept. 28th. The new products are on site and they are being installed as per detail. A second water test will be completed in mid October. The second water test is scheduled to begin on Friday October 30, 2015. The water test has been rescheduled for Thursday Nov. 05,					

			2015. A water test has been completed and water came in around the weather stripping. Marvin has been notified and new weather stripping has been ordered. They will inspect all windows on site for the same issue. A second water test was conducted and water was present around the weather stripping of the windows. An engineer from Marvin Window is going to come to site to determine the issue. Marvin is going to arrange and pay for another water test on the classroom windows when they get completed. A meeting has been scheduled for Tuesday Jan. 19th to discuss various options. It has been dicided that Marvin will produce another window for the project and test the window before shipping it. They will strap and brace the window for shipping and Schooner will install the window. Thermal Wise will then come back to test the installed window.				

7	7/7/15	CLIENT: Scope Change	**1. Delete drapery removals and reinstallation from the contract.** 2. Contractor and Dalhousie to co-ordinate for removals and installation. 3. Dalhousie to hire Drapery Contractor. 4. This will not affect the schedule. 5. A Credit was issued to Dalhousie from the contractor.	7/9/15	-2	$ (1,955.00)	10	**N/A**
8	7/30/15	UNFORESEEN: Concealed Conditions	**1. Additional sandstone repairs.** 2. Identify all required repairs on a drawing showing quantities. 3. Consultant to verify quantities and the client to approve the additional works in a timely fashion. 4. Depending on the quantities it could impact schedule and cost. 5. The quantities are unknown until the work has started on each elevation. The drawing has been completed for the south elevation of the north wing and pricing will be provided soon. Co #2 has been issued for the sandstone repairs on the south	9/16/15	15	$ 19,400.00	10	**N/A**

			elevation of the north wing. Kevin and Robert inspected the sandstone on the East and North elevation of the North Wing and Bradley to provide a cost to do the additional sandstone repairs as per the marked drawing. Bradley provided Robert with the cost breakdown and Robert made some changes from mortar repair to repointing. The cost has been adjusted. CO #4 has been issued for $3,225.00 +Hst.					
9	8/14/15	CLIENT: Non-Scope Change	**1. Classroom(s) Disruption Starting in September.** 2. Move classroom(s) location or schedule noisy work around classroom times. Another option could be to modify the phasing schedule so the work can be completed when classes are out. 3. Client / Contractor to resolve. 4. If classroom(s) can't be moved or the phasing modified then this could impact the schedule and cost. 5. Garry is having a	10/5/15	-15	$ -	10	**SEVERE**

			meeting to discuss possible solutions. The preferred option is to do less wall area and complete the works after hours. A CO will be issued to identify that 25% of less wall area will be completed in Phase 1B for the same cost. CO #5 has been issued. The classroom window installation will take place over the Christmas break starting on Dec. 09, 2015.					
10	9/30/15	UNFORESEEN: Concealed Conditions	**1. Back pointing Quantities can only be determined once the mortar joints are removed.** 2. An allowance has been made in the contract for cost and schedule. 3. The contractor and consultant to keep track of the quantities used on a weekly basis. 4. The cost will be adjusted once each phase is completed and a CO will be issued. 5. The final quantities have been calculated and a CO will be issued to decrease the contract amount by $3,700.00	10/22/15	-4	$ (3,700.00)	10	**N/A**

			plus Hst. A CO Has been received, signed and waiting on owner signatures. The signed CO has been received.					
11	9/30/15	UNFORESEEN: Concealed Conditions	**1. Grouting quantities can only be determined as the work progresses.** 2. An allowance has been made in the contract for cost and schedule. 3. The contractor and consultant to keep track of the quantities used on a weekly basis. 4. The cost will be adjusted once each phase is completed and a CO will be issued. 5. The final quantities have been calculated and a CO will be issued to decrease the contract amount by $11,205 plus Hst. A CO Has been received, signed and waiting on owner signatures. The signed CO has been received.	10/22/15	-8	$(11,205.00)	10	**N/A**

12	11/12/15	CLIENT: Non-Scope Change	**1. After hours work (noisy works).** 2. A cost will need to be added for future phases before PO has been issued. 3. Dalhousie to confirm that this is the route they want to go instead of moving out tenants. 4. This will impact the overall construction cost and should only help out the construction schedule. 5. On the second night of chipping a compliant about the noise was received by Dal Security. After reviewing the HRM By-Law it was determined that no noisy work could go beyond 9:30pm. This will have a negative effect on the overall construction schedule and more so the cost of the project. Pricing has been sent to Dal for the upcoming phases for After Hours (3:00pm - 9:30pm works) and Reduced After Hours Work (4:30pm - 9:30pm).	11/27/15	-55	$ -	10	**SEVERE**

13	12/10/15	CLIENT: Scope Change	**1. Additional Sandstone Repairs on the West Elevation for Phase 2.** 2. Complete an inspection to identify extra work required. 3. Contractor to provide pricing for next years contract. 4. A contingency will need to be carried in next years contract. 5. A budget cost of $110,000.00 was sent for review.	2/1/16	0	$ -	10	**N/A**
14	12/10/15	CLIENT: Scope Change	**1. Additional works on the exterior doors identified for Phase 2 works.** 2. Allow for the repairs to the doors in Phase 2 contract 3. Contractor provided pricing for these works. 4. If approved the cost will need to be included in the phase 2 works. 5.	2/1/16	0	$ -	10	**N/A**
15	12/10/15	CLIENT: Scope Change	**1. South Elevation Courtyard steel brackets for railings rusting and staining sandstone.** 2. A bracket should be removed for inspection and a stain remover applied in a small area for a sample. 3. The consultant will	2/1/16	0	$ -	10	**N/A**

			look at the details once the bracket is removed. 4. A price can only be determined once the methodology for repair is determined. 5. This work will be completed in the spring when the weather improves.					
16	1/14/16	CLIENT: Scope Change	**1. North West Entrance Stairs.** 2. This entrance was not included in the contract documents. 3. Costing was provided to KGA for review. 4. If approved these works need to be included in a future phasing of works. 5.	2/1/16	0	$ -	10	**N/A**
17	1/14/16	CLIENT: Scope Change	**1. Include the remainder of Phase 1B as per original contract.** 2. The Scaffolding is already based out so the snow will not be an issue. 3. Dalhousie to decide if they want to proceed. 4. This will help with the schedule and window installation in phase 2 works. 5. A cost of $75,000.00 was already submitted as part of the night time	2/29/16	23	$ 35,000.00	10	**N/A**

			works. A change order will need to be issued for these works. A cost of $35,000 has been submitted for scaffolding and the 3rd floor Masonry prep works and waiting for a CO to be issued.					
18	1/28/16	CLIENT: Non-Scope Change	**1. Dust and Window Safety Concerns** 2. Plywood will be used to cover over the outside of the windows and additional plastic on the inside. 3. Coastal has already started covering the windows and installing plastic 4. There is an issue with the amount of void found in the cavity of the walls which is contributing to the dust problem and trying to resolve it. 5. The contingency for grouting may not be enough in phase 2 but this wont be known until the actual grouting work begins. Ventilation and fresh air has been supplied for the basement offices to reduce the dust and VOC's that were detected.	2/29/16	3	$ -	10	**SEVERE**

Dalhousie University

Weekly Risk Report

July 17, 2016

Project Number:	**2015-007**	Percent Complete:	
Project Name:	**PHASE 1 - Exterior Envelope Conservation, Henry Hicks**	Overall Client PM Satisfaction:	**10.0**
Project Manager	**Garry Martell**	# Unresolved Risks:	**0**
Vendor:	**Coastal Restoration**	# of SEVERE Risks:	**0**

Cost Analysis		**Schedule Analysis**	
Awarded Cost:	$1,630,479	Awarded Completion Date:	27-Mar-2016
Scope Reallocations:	$0	Scope Reallocations:	0
Current Baseline:	**$1,630,479**	**Current Baseline:**	**27-Mar-2016**
Total Cost Impacts:	-$259	Total Schedule Impacts:	-43
Current Project Cost:	***$1,630,220***	***Current Project Completion Date:***	***13-Feb-2016***
Percent Cost Impact:	***-0.0%***	***Percent Schedule Impact:***	***-13.3%***

Project Schedule Analysis	Number of Risks	Cost Impacts	Schedule Impacts
OVERALL CLIENT IMPACTS	**12**	**$ (4,754)**	**-46**
CLIENT: Scope Change	6	$ 33,045	21
CLIENT: Non-Scope Change	6	$ (37,799)	-67
CLIENT: Innovation / Efficiency	0	$ -	0
OVERALL CONTRACTOR IMPACTS	**1**	**$ -**	**0**
CONTRACTOR: Error / Omission / General Issues	0	$ -	0
CONTRACTOR: Sub / Supplier	1	$ -	0
CONTRACTOR: Innovation / Efficiency	0	$ -	0
OVERALL DESIGN IMPACTS	**0**	**$ -**	**0**
DESIGNER: Error / Omission	0	$ -	0
DESIGNER: Innovation / Efficiency	0	$ -	0
OVERALL UNFORESEEN IMPACTS	**5**	**$ 4,495**	**3**
UNFORESEEN: Concealed Conditions	5	$ 4,495	3
UNFORESEEN: Unexpected Events / Weather	0	$ -	0
OVERALL TOTAL IMPACTS	**18**	**$ (259)**	**-43**

OTHER: Scope Reallocation to/from Separate Project	**0**	**$ -**	**0**

Client Change Order Rate:	-0.3%	Client Schedule Impacts:	-14.2%
Contractor Change Order Rate:	+0.0%	Contractor Schedule Impacts:	+0.0%
Design Change Order Rate:	+0.0%	Design Schedule Impacts:	+0.0%
Unforeseen Change Order Rate:	+0.3%	Unforeseen Schedule Impacts:	+0.9%
Non-Contractor CO Rate:	0.0%	Non-Contractor Delay Rate:	-13.3%

APPENDIXX C – Regression Results

CATEGORY	Sr. No.	Independent Variable	Dependent Variable	R Square	F	P
Overall	1	Risk ID	Cost Impact ($)	0.001	1.521	0.218
	2	Risk ID	Cost Impact (%)	0.000	0.065	0.799
	3	Risk ID	Schedule (Days)	0.008	12.767	0.000
	4	Risk ID	Schedule (%)	0.002	2.848	0.092
	5	Risk RS	Cost Impact ($)	0.001	1.934	0.165
	6	Risk RS	Cost Impact (%)	0.000	0.668	0.414
	7	Risk RS	Schedule (Days)	0.051	80.68	0.000
	8	Risk RS	Schedule (%)	0.046	71.618	0.000
	9	Risk Act	Cost Impact ($)	0.000	0.205	0.651
	10	Risk Act	Cost Impact (%)	0.003	4.799	0.029
	11	Risk Act	Schedule (Days)	0.082	133.97	0.000
	12	Risk Act	Schedule (%)	0.126	216.879	0.000
CLSC						
	13	Risk ID	Cost Impact ($)	0.000	0.020	0.889
	14	Risk ID	Cost Impact (%)	0.003	1.518	0.219
	15	Risk ID	Schedule (Days)	0.096	49.55	0.000
	16	Risk ID	Schedule (%)	0.12	63.861	0.000
	17	Risk RS	Cost Impact ($)	0.000	0.000	0.999
	18	Risk RS	Cost Impact (%)	0.001	0.569	0.451
	19	Risk RS	Schedule (Days)	0.098	50.933	0.000
	20	Risk RS	Schedule (%)	0.137	74.053	0.000
	21	Risk Act	Cost Impact ($)	0	0.117	0.733
	22	Risk Act	Cost Impact (%)	0.003	1.196	0.275
	23	Risk Act	Schedule (Days)	0.001	0.503	0.479
	24	Risk Act	Schedule (%)	0.007	3.277	0.071
CLNSC						
	25	Risk ID	Cost Impact ($)	0.071	6.631	0.012
	26	Risk ID	Cost Impact (%)	0.059	5.434	0.022

	27	Risk ID	Schedule (Days)	0.017	1.509	0.223
	28	Risk ID	Schedule (%)	0.014	1.198	0.277
	29	Risk RS	Cost Impact ($)	0.041	3.75	0.056
	30	Risk RS	Cost Impact (%)	0.038	3.466	0.066
	31	Risk RS	Schedule (Days)	0.021	1.832	0.179
	32	Risk RS	Schedule (%)	0.035	3.198	0.077
	33	Risk Act	Cost Impact ($)	0.005	0.448	0.505
	34	Risk Act	Cost Impact (%)	0.002	0.214	0.645
	35	Risk Act	Schedule (Days)	0.158	16.327	0.000
	36	Risk Act	Schedule (%)	0.197	21.402	0.000
CLIE						
	37	Risk ID	Cost Impact ($)	0.196	1.465	0.272
	38	Risk ID	Cost Impact (%)	0.126	0.862	0.389
	39	Risk ID	Schedule (Days)	-	-	-
	40	Risk ID	Schedule (%)	-	-	-
	41	Risk RS	Cost Impact ($)	0.18	1.314	0.295
	42	Risk RS	Cost Impact (%)	0.107	0.72	0.429
	43	Risk RS	Schedule (Days)	-	-	-
	44	Risk RS	Schedule (%)	-	-	-
	45	Risk Act	Cost Impact ($)	0.003	0.019	0.896
	46	Risk Act	Cost Impact (%)	0.056	0.358	0.571
	47	Risk Act	Schedule (Days)	-	-	-
	48	Risk Act	Schedule (%)	-	-	-
CNE						
	49	Risk ID	Cost Impact ($)	0.000	0.023	0.881
	50	Risk ID	Cost Impact (%)	0.000	0.002	0.969
	51	Risk ID	Schedule (Days)	0.166	9.323	0.004
	52	Risk ID	Schedule (%)	0.209	12.43	0.001
	53	Risk RS	Cost Impact ($)	0.026	1.237	0.272
	54	Risk RS	Cost Impact (%)	0.062	3.087	0.085
	55	Risk RS	Schedule (Days)	0.151	8.375	0.006

	56	Risk RS	Schedule (%)	0.230	14.002	0.000
	57	Risk Act	Cost Impact ($)	0.079	4.026	0.051
	58	Risk Act	Cost Impact (%)	0.242	14.982	0.000
	59	Risk Act	Schedule (Days)	0.000	0.020	0.887
	60	Risk Act	Schedule (%)	0.004	0.179	0.675
CNSS						
	61	Risk ID	Cost Impact ($)	0.008	0.490	0.486
	62	Risk ID	Cost Impact (%)	0.013	0.852	0.359
	63	Risk ID	Schedule (Days)	0.176	13.653	0.000
	64	Risk ID	Schedule (%)	0.151	11.351	0.001
	65	Risk RS	Cost Impact ($)	0.012	0.786	0.379
	66	Risk RS	Cost Impact (%)	0.013	0.855	0.359
	67	Risk RS	Schedule (Days)	0.38	39.264	0.000
	68	Risk RS	Schedule (%)	0.36	36.058	0.000
	69	Risk Act	Cost Impact ($)	0.004	0.281	0.598
	70	Risk Act	Cost Impact (%)	0.001	0.058	0.811
	71	Risk Act	Schedule (Days)	0.233	19.448	0.000
	72	Risk Act	Schedule (%)	0.253	21.661	0.000
CNIE						
	73	Risk ID	Cost Impact ($)	0.001	0.034	0.854
	74	Risk ID	Cost Impact (%)	0.003	0.147	0.703
	75	Risk ID	Schedule (Days)	0.006	0.280	0.600
	76	Risk ID	Schedule (%)	0.006	0.280	0.600
	77	Risk RS	Cost Impact ($)	0.005	0.22	0.642
	78	Risk RS	Cost Impact (%)	0.000	0.002	0.961
	79	Risk RS	Schedule (Days)	0.001	0.067	0.797
	80	Risk RS	Schedule (%)	0.001	0.067	0.797
	81	Risk Act	Cost Impact ($)	0.006	0.296	0.589
	82	Risk Act	Cost Impact (%)	0.005	0.233	0.631
	83	Risk Act	Schedule (Days)	0.002	0.109	0.743
	84	Risk Act	Schedule (%)	0.002	0.109	0.743

DEE						
	85	Risk ID	Cost Impact ($)	0.000	0.000	0.999
	86	Risk ID	Cost Impact (%)	0.000	0.039	0.844
	87	Risk ID	Schedule (Days)	0.011	5.723	0.017
	88	Risk ID	Schedule (%)	0.002	0.817	0.367
	89	Risk RS	Cost Impact ($)	0.000	0.187	0.665
	90	Risk RS	Cost Impact (%)	0.004	1.814	0.179
	91	Risk RS	Schedule (Days)	0.029	14.694	0.000
	92	Risk RS	Schedule (%)	0.027	13.646	0.000
	93	Risk Act	Cost Impact ($)	0.001	0.661	0.417
	94	Risk Act	Cost Impact (%)	0.017	8.330	0.004
	95	Risk Act	Schedule (Days)	0.016	8.231	0.004
	96	Risk Act	Schedule (%)	0.055	28.75	0.000
DEIE						
	97	Risk ID	Cost Impact ($)	0.13	1.646	0.226
	98	Risk ID	Cost Impact (%)	0.253	3.731	0.080
	99	Risk ID	Schedule (Days)	0.073	0.869	0.371
	100	Risk ID	Schedule (%)	0.073	0.869	0.371
	101	Risk RS	Cost Impact ($)	0.272	4.109	0.068
	102	Risk RS	Cost Impact (%)	0.309	4.924	0.048
	103	Risk RS	Schedule (Days)	0.022	0.243	0.632
	104	Risk RS	Schedule (%)	0.022	0.243	0.632
	105	Risk Act	Cost Impact ($)	0.287	4.431	0.059
	106	Risk Act	Cost Impact (%)	0.108	1.326	0.274
	107	Risk Act	Schedule (Days)	0.038	0.437	0.522
	108	Risk Act	Schedule (%)	0.038	0.437	0.522
UNCC						
	109	Risk ID	Cost Impact ($)	0.006	1.365	0.244
	110	Risk ID	Cost Impact (%)	0.012	2.56	0.111
	111	Risk ID	Schedule (Days)	0.024	5.205	0.023
	112	Risk ID	Schedule (%)	0.032	7.128	0.008

	113	Risk RS	Cost Impact ($)	0.009	1.848	0.175
	114	Risk RS	Cost Impact (%)	0.024	5.29	0.022
	115	Risk RS	Schedule (Days)	0.026	5.679	0.018
	116	Risk RS	Schedule (%)	0.047	10.49	0.001
	117	Risk Act	Cost Impact ($)	0.002	0.375	0.541
	118	Risk Act	Cost Impact (%)	0.014	3.02	0.084
	119	Risk Act	Schedule (Days)	0.002	0.387	0.535
	120	Risk Act	Schedule (%)	0.012	2.627	0.107
UNUE						
	121	Risk ID	Cost Impact ($)	0.004	0.192	0.663
	122	Risk ID	Cost Impact (%)	0.004	0.168	0.684
	123	Risk ID	Schedule (Days)	0.004	0.19	0.665
	124	Risk ID	Schedule (%)	0.003	0.126	0.725
	125	Risk RS	Cost Impact ($)	0.008	0.375	0.543
	126	Risk RS	Cost Impact (%)	0.007	0.335	0.566
	127	Risk RS	Schedule (Days)	0.092	4.539	0.039
	128	Risk RS	Schedule (%)	0.110	5.542	0.023
	129	Risk Act	Cost Impact ($)	0.004	0.171	0.681
	130	Risk Act	Cost Impact (%)	0.004	0.162	0.689
	131	Risk Act	Schedule (Days)	0.738	126.758	0.000
	132	Risk Act	Schedule (%)	0.806	187.055	0.000
CLIENT						
	133	Risk ID	Cost Impact ($)	0.002	1.102	0.294
	134	Risk ID	Cost Impact (%)	0.001	0.484	0.487
	135	Risk ID	Schedule (Days)	0.004	2.139	0.144
	136	Risk ID	Schedule (%)	0.000	0.067	0.796
	137	Risk RS	Cost Impact ($)	0.001	0.563	0.453
	138	Risk RS	Cost Impact (%)	0.000	0.102	0.749
	139	Risk RS	Schedule (Days)	0.028	15.972	0.000
	140	Risk RS	Schedule (%)	0.02	11.527	0.001
	141	Risk Act	Cost Impact ($)	0.001	0.358	0.55

	142	Risk Act	Cost Impact (%)	0.001	0.62	0.431
	143	Risk Act	Schedule (Days)	0.054	32.44	0.000
	144	Risk Act	Schedule (%)	0.083	50.972	0.000
CONTRACTOR						
	145	Risk ID	Cost Impact ($)	0.001	0.154	0.695
	146	Risk ID	Cost Impact (%)	0.002	0.282	0.596
	147	Risk ID	Schedule (Days)	0.11	19.907	0.000
	148	Risk ID	Schedule (%)	0.102	18.37	0.000
	149	Risk RS	Cost Impact ($)	0.007	1.086	0.299
	150	Risk RS	Cost Impact (%)	0.000	0.016	0.899
	151	Risk RS	Schedule (Days)	0.177	34.511	0.000
	152	Risk RS	Schedule (%)	0.189	37.559	0.000
	153	Risk Act	Cost Impact ($)	0.011	1.75	0.188
	154	Risk Act	Cost Impact (%)	0.008	1.305	0.255
	155	Risk Act	Schedule (Days)	0.058	9.852	0.002
	156	Risk Act	Schedule (%)	0.083	14.569	0.000
DESIGNER						
	157	Risk ID	Cost Impact ($)	0	0.015	0.901
	158	Risk ID	Cost Impact (%)	0	0.012	0.914
	159	Risk ID	Schedule (Days)	0.011	5.525	0.019
	160	Risk ID	Schedule (%)	0.002	0.816	0.367
	161	Risk RS	Cost Impact ($)	0.001	0.37	0.543
	162	Risk RS	Cost Impact (%)	0.004	2.158	0.142
	163	Risk RS	Schedule (Days)	0.028	14.737	0.000
	164	Risk RS	Schedule (%)	0.026	13.36	0.000
	165	Risk Act	Cost Impact ($)	0.002	0.851	0.357
	166	Risk Act	Cost Impact (%)	0.017	8.838	0.003
	167	Risk Act	Schedule (Days)	0.017	8.903	0.003
	168	Risk Act	Schedule (%)	0.053	28.29	0.000

UNFORESEEN

169	Risk ID	Cost Impact ($)	0.001	0.349	0.555
170	Risk ID	Cost Impact (%)	0.004	0.922	0.338
171	Risk ID	Schedule (Days)	0.000	0.129	0.72
172	Risk ID	Schedule (%)	0.000	0.015	0.903
173	Risk RS	Cost Impact ($)	0.002	0.511	0.475
174	Risk RS	Cost Impact (%)	0.009	2.326	0.128
175	Risk RS	Schedule (Days)	0.065	18.268	0.000
176	Risk RS	Schedule (%)	0.071	19.972	0.000
177	Risk Act	Cost Impact ($)	0.000	0.119	0.73
178	Risk Act	Cost Impact (%)	0.007	1.864	0.173
179	Risk Act	Schedule (Days)	0.273	98.317	0.000
180	Risk Act	Schedule (%)	0.333	131.026	0.000